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NASA TECHNOLOGY APPLICATIONS

HEARING

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

APRIL 13, 1989

[No. 47]

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CONTENTS

WITNESSES

April 13, 1989:

Page

- Hon. Wes W. Watkins, a Representative in Congress from the State of Oklahoma 3
- James T. Rose, Assistant Administrator for Commercial Programs, NASA 12
- The Programmable Implantable Medication System; Robert E. Fischell, Chief, Technology Transfer, Applied Physics Laboratory, Johns Hopkins University, Laurel, Maryland 22
- The Programmable Implantable Medication System; F. Jackson Piotrow, School of International Services, The American University, Tenley Campus, Washington, DC 37
- The Stirling Engine; A. Gregory Gutgsell, Executive Program Manager, Government Products Operations, Deere & Company, Moline, Illinois 56
- The Stirling Engine; Thomas M. Kennedy, Jr., President, The Kennedy Engine Company, Inc., Biloxi, Mississippi 64
- The Intelligent Tutoring System; Robert Savely, Chief, Artificial Intelligence Section, LBJ Space Center, Houston, Texas 70
- The Intelligent Tutoring System; Bowen Loftin, Department of Physics, University of Houston, Houston, Texas 84
- The Monterey, Virginia Sewage Treatment Center; Billy C. Wolverton, Senior Research Scientist, John C. Stennis Space Center, Bay St. Louis, Mississippi 88
- The Fire Fighters Breathing System; Chief James Manahan, NYFD Safety Battalion, NYC Fire Department 107
- The Power Factor Controller; Mr. George Halas, Manager, Sales Department, Nordic Controls Division, Furnas Electric Company, Batavia, Illinois 129
- The Robotic Sow; Cullum Johnston, Farmatic, Inc., London, Ontario, Canada 139
- A Portable Gas Leak Detector; Robert Turner, President, Microsensor Technology, Inc., Fremont, California 143
- A Fire Fighter's Ensemble; Joseph Vita, Occupational Health and Safety Department, International Association of Fire Fighters, Washington, DC 146
- Ovation Guitars; C. William Kaman, President, Kaman Music Corp., Bloomfield, Connecticut 147
- The Virtual Environment Work Station; James Larimer, Chief, Human Interface Research Branch, Ames Research Center, Moffett Field, California 152
- The Electro-Expulsive Separation System; Leonard Haslim, Project Manager, NASA Ames Research Center, Moffett Field, California 158
- UV Filtered Lenses; Alan Mittelman, President, Sun Tiger, Inc., La Crescenta, California 163
- Metallized Products; Patrick McHugh, Metallized Products, Inc., Winchester, Massachusetts 167
- The Computational Fluid Dynamics/Artificial Heart Flow; Paul Kutler, Chief, Fluid Dynamics Division, Ames Research Center, Moffett Field, California 171
- The Temperature Pill; Russ Eberhart, Program Manager, Biomedical Program Office, Applied Physics Laboratory 176
- Automated Implantable Defibrillator; M. Steve Heilman, President and CEO, Vascor, Inc., Pittsburgh, Pennsylvania 179

Page

April 13, 1989—Continued

Below Elbow Prothesis; Jewell "Pete" Belcher, Project Engineer, Marshall Space Flight Center, Huntsville, Alabama 189

The Aquaspace Water Filter; Mike Pedersen, President, Western Water International, Forrestville, Maryland 197

The Bon Del Water Filter; Ray Ward, President, Water Filter Company of America, National City, California 199

NASA TECHNOLOGY APPLICATIONS

THURSDAY, APRIL 13, 1989

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D. C.

The subcommittee met at 9:30 a.m. in Room 2318 of the Rayburn House Office Building, the Honorable Bill Nelson, chairman of the subcommittee, presiding.

Present: Representatives Nelson, Sensenbrenner, Schiff, Packard, Rohrabacher, Morella, Perkins, Stallings, Nagle and Smith of Texas.

Also PRESENT. Wes Watkins, Doug Walgren, Jim Olin and Michael Andrews.

Mr. NELSON. Good morning.

You know, I think I'm going to do something different today, Jim. I'm going to turn to you for the opening statement.

Mr. SENSENBRENNER. Well thank you very much, Mr. Chairman. I don't have a prepared opening statement, but I welcome this hearing today in showing the public the very practical applications of what we have discovered through the space program.

As we all know, the space program has spent billions of dollars of the taxpayers' money and the budget request for Fiscal 1990 is 13.2 billion for NASA. And very frequently a lot of members of Congress are asked exactly what does that get us, aside from national prestige. This morning we see a lot of the things that the space program has gotten us. And they're things that have made the quality of our life better, advances in medical science that have lengthened our expected longevity, as well as things that make us enjoy life better. So I think that these kinds of very practical applications of the space program demonstrate that the money that Congress has appropriated in the past and will appropriate in the future has really done the American public and each of us individually a lot of good.

So thank you for having this hearing and I am looking forward to the testimony.

Mr. NELSON. Well this is going to be an exciting time. I want to show you something:

This is one of the better investments I've ever had. That watch cost me $19. I bought it four years ago. I woke up this morning to it. I did my timed jog with it this morning. Three years ago I punched off that watch at T minus 0 and I watched our ascent all the way to 8.5 minutes MECO, Main Engine Cut Off. Did a number of the timed experiments on orbit with it.

The long and short of it is that that watch is a technology spinoff from America's space program in which we did the micro-miniaturization, particularly when we went to the moon. There we had to have highly reliable systems that had to be light in weight and small in volume. And from that has come the micro-miniaturized computers that have transformed our daily lifestyles, that have led us to the super minicomputers that give us a better quality of life in our day-to-day activities, not the least of which is the Programmable Implantable Medication System, having been implanted in a patient at Johns Hopkins now for a couple of years. A lot of people in America do not realize the spin-offs and the technology utilization from America's space program. And so that's what this hearing is all about.

This hearing is going to be a lot of fun. We're going to learn a lot. We are actually going to touch and feel as we experience today, throughout the course of the day in this technology utilization.

Mr. Schiff?

Mr. SCHIFF. Mr. Chairman, I wonder if I might respectfully ask if you would yield to a question from me?

Mr. NELSON. Certainly.

Mr. SCHIFF. Who manufactured the watch that you were just talking about?

Mr. NELSON. Well do we want to give that out and actually have a commercial—

Mr. SCHIFF. Well maybe I should rephrase the question: In what country was the watch manufactured that you're referring to, Mr. Chairman?

Mr. NELSON. Why don't you go ahead and give us the commercial of how more of that ought to be done here at home.

[Laughter.]

Mr. SCHIFF. I think I just did, Mr. Chairman. Thank you very much.

Mr. NELSON. That might be a consideration that we ought to use in this coming debate on the FSX, as a matter of fact.

That underscores a very important point: that often the research and development is done here in America, but the technology application is done elsewhere.

Go ahead.

Mr. SCHIFF. I don't want to belabor this to the detriment of the witnesses' time, Mr. Chairman, but I think that was one of the points made in the Full Committee hearing by a witness, Professor Roy, who said that we are spending a great amount of money on basic research but it is not our country that is now set up to translate that basic research into commercialization.

Mr. NELSON. Well these spin-offs that we're going to look at today have become deeply entrenched in our lives, they cut across every part of our daily lives in diverse fields as agriculture and education, transportation, in medicine, in aids for the handicapped and the disabled, even in entertainment, and we see a number of musical instruments back here that we're going to learn some of the technology utilization there.

We're going to see today how some of these technology spin-offs have an application to our economic engine here in America. And we're going to hear about how some of these have become multi-million dollar operations. We're going to hear about the small and the medium size companies that definitely have an interest in technology utilization but don't have the R&D budgets and therefore how can we draw the link between government and NASA R&D and them.

Well these spin-offs are going to speak for themselves, and it's going to be an exciting day.

Now we're going to conduct this hearing in two parts: we will begin with presentations by some of our witnesses up at the front of the room and we'll have demonstrations of their products. And so when we get to that point, we'll have you coming to the actual hardware and up to the front table.

Following the presentations, the members, the staff, the press and the public will be invited to walk around the room and individually inspect these spin-offs, ask questions and participate in a hands-on kind of demonstration. We want your participation today.

Please also note that during this time the two examples of the Stirling engine will be available in the Rayburn horseshoe for inspection and test drives.

Now we have an extensive witness list, all of them will be fascinating for us, so I'm going to, since we have an extensive witness list, ask our witnesses if they will be brief.

We are going to have the pleasure of hearing from one of our colleagues to begin with, and I would like to call on the gentleman from Oklahoma, Mr. Watkins, and then we will go to Mr. Rose.

Mr. Watkins.

STATEMENT OF WES W. WATKINS, REPRESENTATIVE IN CONGRESS FROM THE STATE OF OKLAHOMA

Mr. WATKINS. Thank you, Mr. Chairman, Jim, and other distinguished members of the Committee. I'm delighted to be back. I'm going to keep my remarks very brief because I know that you've got an extensive program and so I'll try to make a couple of points that I hope maybe you'll jot down and make sure that they're looked at and hopefully in the legislation when it's authorized.

Mr. Chairman, I don't have to say to you my interest has been long-time in this. In fact, ten years prior to coming to Congress when I was writing an overall economic development plan for my area of Oklahoma, I became involved with technology transfer and what it could mean, technology utilization, so those small organizations TU and IAC, which is now located in Durant, Oklahoma with Rural Enterprises.

Then I became a member of this Subcommittee when I first came here and I really became interested from the standpoint of seeing and trying to work on some of the languages and shaped Chapter 11 of the Stevenson-Wydler Act in order to try to get more of our groups and agencies and laboratories involved in technology transfer and technology utilization.

So I just make that comment from the introduction to the other members and staff to know that my heart is in this, it's not just a political situation, because I think you can see the results of a lot of these activities that can take place and many more to come in the future.

Mr. Chairman, I'd like to make a couple of points along this way:

We've been doing this and we've been putting together what is called a full court press in basketball about every angle of trying to provide technology evaluation, marketing, gap technologies, gap financing and all in combination—along with the technology utilization effort.

Technology utilization should be more than technology dissemination. Technology utilization should include more of a program to help get technology transfer into the hands of small businesses in a pro-active way, not a passive way. That's the thing.

And there is a difference. If you just wait for the person to walk in off the street, you'll get a few, yes. Or you can set up a program that would actually generate and cause things to happen. And I'm a believer of that as a businessman, before I got here, Bill, like you, I believe that we should calculate and see how efficient and how effective we are.

And by that, let me give you a couple of examples of what I think we can do to help in that area:

Mr. Chairman, I fully believe that fees should be charged. Subscribers, industries, others should pay a little bit of a fee to try to have assistance in getting technology.

But here is a very important point: right now when those fees are paid to an IAC, then that is taken away from their contract and not allowed for them to add it to their additional services in keeping their program to help develop that organization to provide more extensive help. And a lot of the government agencies when fees are charged are able to be maintained within that agency or that program to be able to assist. That is deducted from any contract that goes to an IAC from their contract that they have. That takes away the incentive for them to go out and really push the subscribers in getting more industry involved in doing that. It's the old private enterprise type effort, we take that away.

We need to make sure in the IAC's in the technology utilization effort that that is left there as an incentive and those fees can be utilized by that entity, that IAC, wherever it may be. So that's one of the things, it's a very little practical thing but, Bill, I think you and I probably truly believe in that free enterprise system and that opportunity to see incentives happen and I think we'll get a multitude of more effort and activity out of these IAC's if that would be made possible by the legislation you have at your fingertips to make it come about.

So I make that point as one of the key ones. And also to make sure that we don't just look at technology dissemination but say are we putting the building blocks in there for the technology transfer. You can see some of the results, it can multiply even far greater.

Because I've said time and time again: if we're going to maintain the support for the space program, outer space, we've got to prove to the people what we're doing here on earth is benefitting their lives. I think you've got an example today of that that you're going to be able to show the entire United States.

And many of the media people here I hope will take this—your program today, your hearings, and elaborate on it, get your testimony and others and be able to tell this great country what a great job NASA is doing and also the great job of a technology utilization program is taking place in this country, not only doing but, Mr. Chairman, I hope that you'll insist that it be able to expand.

So thank you for allowing me to come by. I will make my regular remarks here a part of the record, if it's all right with you, and that's my particular testimony for today.

[The prepared statement of Mr. Watkins follows.]

STATEMENT OF
CONGRESSMAN WES WATKINS

REGARDING
NASA'S TECHNOLOGY UTILIZATION PROGRAM

BEFORE THE
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

APRIL 13, 1989

Mr. Chairman and Members of the Committee:

Thank you for allowing me the opportunity to appear before you today to express my support of, and recommendations concerning, NASA's Technology Utilization program.

As you know, I have been a staunch supporter of technology transfer and technology utilization since the days when I served as a member of this committee. As the author or Chapter 11 the Stevenson-Wydler Technology Innovation Act of 1980, and I am proud of this committee's continued support for federal technology transfer programs.

The Technology Utilization (TU) program at NASA is an outstanding program, and one that ought to be continued and expanded.

The TU program's Industrial Applications Centers (IACs) need to be supported with solid federal financial assistance and expanded into multi-service, hands-on, aggressive programs such as exists at the Central Industrial Applications Center (CIAC) at Rural Enterprises, Inc., (REI) in Durant, Oklahoma.

REI/CIAC provides services to clients in technology evaluation, marketing, gap technologies, and gap financing using a multitude of federal, state, and private data bases and resources. Providing searches for available federal technologies to businesses is not enough.

A comprehensive, full-court press is needed to commercialize federal technologies to the extent needed by American businesses and the American economy. Improvement of American competitiveness in a world economy requires such a federal initiative and investment.

The TU program leads the nation in technology evaluation, dissemination, application, and commercialization. It is the standard by which all other federal technology transfer efforts are measured. It needs to be supported and strengthened, to include marketing, gap technology and gap financing assistance.

Technology transfer is finally being taken seriously as a mandate of the federal government beyond the walls of NASA. The Department of Energy, Department of Commerce, Department of Defense, and the Small Business Administration, amongst others, have apparently suddenly seized upon the concept of technology transfer as a positive initiative, for which they should be commended.

The application of federally-developed technologies in the private sector should be a permanent, on-going responsibility of all federal agencies involved with technology or research of any kind. We should rejoice at the new-found enthusiasm in federal agencies to begin pro-active programs to find applications in the private sector for federal technologies.

Federal agencies other than NASA should not, however, be permitted to waste scarce federal resources by establishing technology transfer networks totally separate from the highly successful network already established by NASA. Other federal agencies should be required to work in concert with NASA, building upon the resources off NASA's existing applications teams, industrial application centers, and field offices.

We all know how difficult is is sometimes to get federal agencies to work together toward a common cause, but we must require close coordination between departments in the area of technology transfer. The last thing American business needs is a fragmented, duplicative, uncoordinated federal technology transfer thrust that turns into nothing more than a bureaucratic turf battle.

There are signs that such battles have already been waged, and I urge this committee to act firmly and swiftly to curtail administrative infighting, power struggles, and duplicative dessimination networks as quickly as possible. Out nation's economy demands development of a well coordinated, government-wide technology transfer initiative. NASA's proven TU program should serve as the basis of the government-wide initiative.

A Rural Applications Team has long been part of NASA's Technology Utilization program, and I urge the Committee to continue the designation of this rural component as part of the reauthorization of the Technology Utilization program. The Rural Applications Team has been extremely beneficial to small businesses in Rural America.

NASA's Industrial Applications Centers also provide invaluable assistance to businesses searching for solutions to technology problems. The IACs have established solid public-private partnerships for financing the cost of conducting technology searches. Fees are charged for technology searches at reasonable rates according to the size of the business involved and its ability to pay.

The charging to fees for IAC technology searches ought to be strongly supported, within reasonable limits. It helps finance IAC operations, helps reduce the federal cost of the TU program, and helps IACs weed out frivolous requests for assistance.

IACs should be allowed to retain fee income for investment in their program, rather than have their federal contract funding reduced by the amount of their fee income, as occurs now with at least some of the IACs. The IACs have no incentive to seek fee income if it does not result in a positive effect on their operating budgets. To the contrary, the increased paperwork for accounting for the fee income does, in fact, discourage the entire fee income concept.

The fee income issue needs to be resolved so that IACs benefit, and thus have an incentive, to collect search fees whenever possible.

Finally, Mr. Chairman, I ask you and the other members of this Committee to increase technology transfer funding from 0.5 percent to at least 1.0 percent of the federal laboratories' research budgets. That is a small price to pay for greatly increased technology competitiveness of American businesses.

Mr. Chairman, I remain committed to enhancing technology transfer efforts as a responsibility of the federal government. I commend you for holding this special TU Technology Spin-offs hearing today. The public needs to be made better aware of the great benefit of the space program to inventions that impact our lives every day.

Thank you for allowing me to testify before you today. I would be happy to respond to any questions.

Mr. NELSON. Mr. Watkins, you are always welcome. You are always a breath of fresh air. We love to have you come because you give us that down home kind of flavor of application of the highfalutin' R&D right to every day life and we appreciate that.

We need a little help from you. You're a member of the Appropriations Committee and we've got a little matter in front of the Appropriations Committee—

Mr. WATKINS. I'd have been disappointed if you had overlooked that.

[Laughter.]

Mr. NELSON. I think that, you know, it's going to resolve itself on the little problem that has arised over Fiscal Year '89 and the supplemental funding bill for Fiscal Year '89 but we just can't take any chances, and so I wish that you would confer with Chairman Bob Traxler and some of the concerns that they have.

And then, as we look on to Fiscal Year '90 and the crunch is coming again and we've got an artificial situation created where NASA and the civilian space program are having to compete with the Veterans' Administration and the Small Business Administration and Housing and Urban Development Department in an artificial way of competition because those funds are allocated to that Appropriations Subcommittee.

Mr. WATKINS. Yes.

Mr. NELSON. And that shouldn't be the way it should be. We should say, "Is this, this and this a priority in our funding." And if it is, then we ought to go out and fund it.

Mr. WATKINS. Mr. Chairman, you've got a very good point. I testified before the Veterans on the situation they confronted. Mr. Chairman, you're right. But Gramm-Rudman is forcing that. And the new programs coming on board adding on top of it is creating a crunch, and I think all people need to know that, you know, Gramm-Rudman is alive and real and it's forcing only bad choices.

I'll be happy to talk to Chairman Traxler. I would also encourage, Mr. Chairman, you and the members: go to him and say, "Fine, maybe you can suggest where some money can be taken from some other areas of the space program or otherwise some other places for technology utilization." Because I'm not as knowledgeable about all facets of the space programs and other areas. I do know this: if we don't have the support of technology utilization for the people here on earth, we're not going to have a space program out there in orbit some time in the near future.

Mr. NELSON. Now your point is very well taken. And it's another interesting phenomenon that we find ourselves in the government sector under the same kind of pressure when you have to cut a budget as corporations find in the private sector. Where is often the place that they cut first? Research and development.

Mr. WATKINS. That's right.

Mr. NELSON. And yet that is our seed core.

Mr. WATKINS. That's right.

Mr. NELSON. We've got to set that aside for the planning for the future. We can't go eat our seed core.

Mr. WATKINS. You're totally right. You are preaching to the choir. You're right.

Mr. **Nelson**. Well you're always a delight to have here, Mr. Watkins.

Mr. **Watkins**. Let's go quote them some chapters and scriptures and verses and we'll let them get back on track with technology utilization.

Mr. **Nelson**. All right. You get over there to the Appropriations Committee and start preaching—

[Laughter.]

Mr. **Nelson**.—and I'll come along and I'll lead the choir and we'll see if we can have a real good service.

Mr. **Watkins**. Great. Thank you.

Mr. **Sensenbrenner**. Would the gentleman yield?

Mr. **Nelson**. Certainly.

Mr. **Sensenbrenner**. The last time I read the scripture, there was a beatitude that had a great deal of application to this situation. It's called blessed be the peacemaker, for he shall catch hell from both sides.

[Laughter.]

Mr. **Watkins**. Thank you, Jim, I'll go look that up. I don't think I've read that one yet.

Mr. **Nelson**. It does say something about inherit the earth.

Mr. **Watkins**. Thank you, Mr. Chairman, very much.

Mr. **Nelson**. Thank you, Mr. Watkins.

Mr. Rose.

STATEMENT OF JAMES T. ROSE, ASSISTANT ADMINISTRATOR FOR COMMERCIAL PROGRAMS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. **Rose**. Mr. Chairman, other members of the Committee—Subcommittee. After two days ago, I'm glad to be back again, this time to discuss the technology transfer program.

I don't think it's any question but that the civil space program has served as a major focal point for technology development. I don't think it's any question that this technology has also had many applications, and I think every economic study that's been conducted on that subject has shown that for every dollar that has been invested in our civil space program there has been a healthy return on investment to each and every person in the country in terms of applications which have improved our lives immeasurably, and in fact we're going to try to show you some of those things today.

In fact, there are estimates that there have been over 30,000 real applications derived, and we are trying to substantiate that number, because we are continuing to do more and more work to try to quantify exactly what this applications program has done. We think it's important—just as Congressman Watkins said, we need to get the message out. We need for people to better understand that if we're going to compete internationally, high technology is a major element of that competition and the space program is a way to focus our energies on developing technology that will have direct applications.

So we're pleased to have today a number of important witnesses and other guests who are here to tell you about some of those applications and to give you a feel—in the public, a feel for what it is that we are able to produce from space technology.

And so, without any more—unless you desire some questions, I'm going to start the process. Because I think that's what we're here to see, these technologies.

[The prepared statement of Mr. Rose follows.]

'2 #2

NASA

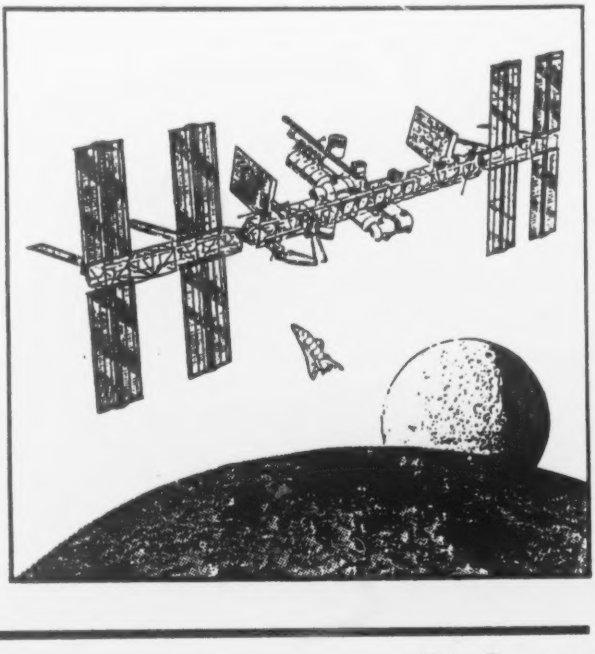
National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witness

April 13, 1989

Subcommittee on Space Science and Applications Committee on Science, Space, and Technology

House of Representatives



Statement by:

James T. Rose
Assistant Administrator
for Commercial Programs

101st Congress

Hold for Release Until
Presented by Witness
April 13, 1989

Statement of

James T. Rose
Assistant Administrator
Office of Commercial Programs
National Aeronautics and Space Administration

before the

Subcommittee on Space Science and Applications
Committee on Science, Space and Technology
House of Representatives

Mr. Chairman and Distinguished Members of the Subcommittee:

In my testimony before this Committee on April 11, 1989, I described in some detail recent accomplishments and proposed infrastructure enhancements of NASA's technology transfer efforts for the FY 1990 budget year. This past year marked the 25th anniversary of NASA's Technology Utilization Program, a program designed to transfer the results of aerospace research and development (R&D) to meaningful uses in the Nation's economy. I am pleased to be here today to discuss and demonstrate some of the most exciting aspects of this program, the technology spinoffs and applications projects.

NASA research programs represent a leading source of new technology. Because aerospace programs are, by their challenging nature, extraordinarily demanding of technological input, the innovations they generate are exceptionally diverse. Because it can be readily transferable, the technology being developed today provides a wellspring of know-how for new applications tomorrow.

NASA programs of the past three decades have created a vast wealth of already-developed technology that is available now for use by U.S. industry in creating new products and processes. It is a natural resource that can be put to work to enhance national productivity and competitiveness. Its importance is underlined by the fact that more than 30,000 secondary applications of this technology - spinoffs - have emerged to the benefit of the Nation's lifestyle and economy.

Over the past 25 years, technologies have spun off from NASA R&D programs into such fields as health and medicine, public safety, energy, transportation, environmental protection, and many diverse areas of industrial manufacturing.

NASA technology has played a vital role in the development of many life-saving medical applications such as:

- A rechargeable cardiac pacemaker, manufactured by Mini-Med Technologies, that eliminates the recurring need for surgery to replace batteries;
- A human tissue stimulator that provides relief from chronic pain by sending electrical impulses to targeted nerve centers. The stimulator was developed by Pacesetter Systems, Incorporated, in cooperation with the Applied Physics Laboratory of Johns Hopkins University;
- A family of civil-use fluid control devices, such as a filtering system that removes impurities from blood; and
- A cradle whose electricity-conducting canopy provides controlled radiant heat to warm newborn premature babies without noise or burn hazard. Cavitron Corporation, KDC Medical Sales, is the manufacturer.

In addition, NASA has worked routinely with the National Institutes of Health and the Veterans Administration in developing new approaches and techniques to rehabilitate the handicapped.

The field of public safety has especially benefited by transfer of aerospace technology. Some examples include:

- A sophisticated smoke/fire detection system, manufactured by Carl Byoir and Associates, Incorporated, used in the home as a detection/warning device;

- An underwater device, produced by Burnett Electronics Laboratory, that signals the location of a downed airliner's flight recorder;

- An X-ray inspection system for examining luggage at airports and other security areas; and

- A thin, lightweight, flexible fire resistant fabric used in fire-entry suits for fire-fighters and industrial workers exposed to high heat, steam, or hot liquids.

Several aerospace technologies have found spinoff utility in environmental and resources management applications such as:

- Geology, archeology, and pipeline monitoring; and

- Many types of coatings with superior corrosion resistance (the Statue of Liberty wears a NASA-developed interior coating).

NASA spinoffs have also impacted the food and agriculture industries through such technology developments as:

- A fishing net, manufactured by West Coast Netting Company, that sinks faster and arrives at its fishing depth quicker than conventional nets thus trapping extra tons of fish; and

- A microwave system, developed by McDonnell Douglas, that dries agricultural crops with less chance of quality loss and a lower energy requirement than hot-air blowers.

Aerospace technology is being put to productive use in industrial facilities. Examples include:

- Perfectly spherical plastic beads, grown in gravity-free space, that serve as reference standards for calibrating instruments with extreme accuracy. The microspheres are produced by TSI, Incorporated; and

- An air flotation system, manufactured by Rolair Systems, Incorporated, that allows heavy loads to "float" over the plant on air bearings.

Space-pioneered energy technology has found wide usage in Earth heating, cooling, and electricity-generating applications such as:

- Heat shield insulation that offers dramatic energy savings for homes and office buildings;

- Compact, no-moving-parts, heat pumps which keep the ground near the Alaska pipeline permanently frozen, protecting against pipeline ruptures that could cause economic loss or environmental disaster. The heat pumps are manufactured by the Alyeska Pipeline Service Company; and

- A controller for electric motors which senses a motor's load and feeds it only the minimum voltage it needs to do its job, hence sharply cutting power wastage.

Important gains in economy, safety, and construction simplification have been made as a result of NASA spinoff technology. Examples in the construction field include:

- A line of cordless tools and instruments, based on technology-developed for a lunar subsurface drill, which includes self-contained construction tools for use where a power source is not readily available. Black and Decker is the manufacturer.

- A special fabric, originally developed for space suits, which is thin, light, flexible, yet durable and noncombustible and can be an inexpensive roofing alternative for shopping malls, stadiums, field houses, schools, theaters, exhibit halls, and industrial facilities. The fabric is produced by Owens-Corning Fiberglass Corporation.

These are but a few of the many technological spinoffs from NASA that are helping promote health, save lives, and increase productivity. As NASA embarks on a new generation of space exploration, there will undoubtedly be many new and important spinoffs. From the Space Station Freedom Program alone, NASA developments in outfitting the Health Maintenance System and the Life Sciences Laboratory offer new technologies for small, simpler, and more advanced diagnostic instrumentation and computerized health information management systems. In fact, NASA, through its Technology Utilization Program, has already teamed with several other organizations to design and develop an advanced instrument which will increase the capability for precise measurement of cells and cellular constituents. This will allow for improved analysis of immunological deficiencies, improved management of cancer therapies, and many other important applications.

One facet of NASA's Technology Utilization Program is an applications engineering effort involving use of NASA expertise to redesign and reengineer existing aerospace technology for the solution of problems encountered by federal agencies, other public sector institutions or private organizations. The following items are examples of on-going applications efforts:

- A locator system that will alert drivers with impaired hearing when an emergency vehicle is approaching. The device will detect the siren of an approaching ambulance or fire truck and display a signal on the driver's dashboard, indicating not only the sound, but direction and distance of the approaching vehicle. This will then enable the driver with hearing difficulties to pull over or take evasive action.

- An effort to improve the sight of some 2.5 million people in the U.S. who suffer from "low vision," visual impairment that cannot be corrected medically, surgically, or by conventional prescription eyeglasses. Still in an early stage, this project contemplates use of space-derived computerized image enhancement technology to alter and enhance images to compensate for the low vision. The planned Low Vision Enhancement System will resemble "wraparound" eyeglasses and will custom tailor images of the outside world. The patient will see the world on miniature television screens where the lenses of eyeglasses are normally located.

A stabilized observation instrument platform for public service helicopters. This instrument would enable, for example, police or antidrug agencies to observe ground activity from a remote, undetectable vantage point. The problem with existing equipment is that vibration from the helicopter's rotor system makes it difficult to use lenses with long focal lengths because the vibration distorts the imagery from the observing instruments.

In closing, I would like to briefly reiterate the Technology Utilization budget request for FY 1990. We are requesting $22.7 million for the program in FY 1990, which money will be used to accomplish the following activities:

(1) broadening of application projects to assist NASA Industrial Application Centers (IAC) in bringing together industrial client problems with existing aerospace technologies, leading to project definition and industry-driven cooperative projects, thus enhancing the productivity and competitive posture of U.S. industry;

(2) improving the capability of the technology utilization offices at the NASA field installations to increase the level of technology transfer activities by means of a microcomputer-based system that efficiently stores data and facilitates timely access to new technologies developed in NASA's R&D programs. This network, the Technology Utilization Network System (TUNS), completes the linkage of the NASA technology utilization field installation offices, the NASA Software Repository (COSMIC), the NASA Scientific Technical and Information Facility (STIF), and IAC's to provide a quicker distribution of new technologies than has previously been possible;

(3) increasing new technology identification, evaluation, reporting, and more efficiently packaging these new technologies for publications, thereby stimulating increased industrial interest and participation in NASA's Technology Utilization and Commercial Use of Space Programs;

(4) increasing the utilization and expanding the role of NASA's IAC's as a unique network to serve as NASA's surrogate in aligning U.S. industrial interests in space commercialization as well as opportunities for terrestrial commercialization of advanced technologies derived from NASA's R&D programs; and,

(5) promoting awareness of NASA's Technology Utilization Program and resources available to the public and private sectors through a broad array of program materials, seminar, and conferences. Industrial outreach will be expanded by efforts to identify additional nonaerospace users of NASA's technologies.

This concludes my prepared remarks, Mr. Chairman. I would be pleased to respond to questions.

Mr. **Rose**. Our first panel—we're going to have some seven panels of discussions and then we'll go around the room with brief discussions of what some of the other technologies are, but our first panel is relating to what we call a Programmable, Implantable, Medication System, which is now being used by diabetic patients. Our two panelists are:

Dr. Robert E. Fischell, he's Chief, Technology Transfer, Applied Physics Laboratory at Johns Hopkins University in Laurel Maryland, and Dr. F. Jackson Piotrow, from the School of International Services, the Tenley Campus, the American University, Washington, D.C.

Mr. **Nelson**. Come on up gentlemen and have a seat.

While they're coming up, do you want to make a quick editorial comment about Admiral Truly's nomination?

Mr. **Rose**. Well I'm just delighted. I think Dick Truly has grown significantly in the job of running our shuttle and space flight programs and I just think he's going to be—have the energy and be super-sensitive to the future needs of this country in running the NASA program and so I'm delighted.

Mr. **Nelson**. I'm very, very encouraged. I think he's going to be an excellent leader.

Mr. **Rose**. I do, too.

Mr. **Nelson**. Okay, gentlemen.

Mr. Fischell.

STATEMENT OF ROBERT E. FISCHELL, FORMERLY CHIEF, TECHNOLOGY TRANSFER, SPACE DEVELOPMENT, APPLIED PHYSICS LABORATORY, JOHNS HOPKINS UNIVERSITY LAUREL, MARYLAND, PRESENTING THE PROGRAMMABLE, IMPLANTABLE, MEDICATION SYSTEM

Mr. **Fischell**. Mr. Chairman, distinguished members of the Committee, ladies and gentlemen.

The Space Act, which resulted in NASA's creation, conceived of the application of space technology spin-offs to directly benefit mankind.

This morning I'll describe to you an excellent example of one such transfer of space technology into medicine. From the outer space of earth satellites to the inner space of diabetic patients in whom we have now implanted computer-controlled programmable insulin pumps that mimic the human pancreas.

And, as a matter of fact, Dr. Piotrow, who is sitting next to me, has such an implantable computer-operated artificial insulin pancreas in him and later on he's going to give you a live demonstration of how it works to approximate the action of a normal pancreas.

But let me—if I may have the first slide, please, and could you lower the screen...

[Pause.]

I think that most people are not really aware of the serious complications of diabetes.

[Slide.]

The long-term complications of diabetes are many. About 5,000 a year become blind; 20 percent, which is one—of all the diabetic patients, have kidney failure, that constitutes one third of all the patients on kidney dialysis; 50 percent of all limb amputations and 40 percent of all males become sexually impotent; and it's a major health risk for heart disease and stroke; a high incidence of pregnancy complications and birth defects and, what a lot of people don't realize is that two million diabetics are hospitalized each year.

So insulin does not cure diabetes. It is a disease which has certain progression. And which the fact that we cannot, with an injection, mimic a pancreas, that got me to work on this particular project.

[Slide.]

This next slide shows a device that existed before we applied space technology. This happens to be a pregnant diabetic lady wearing a pump. The pump was about 12 inches long, four inches across and weighed about six pounds. But if she carried it with her and injected insulin under her skin, she had a better chance of having a normal child, being a pregnant diabetic, than if she did not have it.

[Slide.]

We got some very interesting results from measuring other things besides blood sugar on these patients. In particular, cholesterol levels, triglycerides, free fatty acids, all these things which cause heart disease and stroke in the diabetic more than the other person were found to be dramatically reduced on pump therapy compared to simple injection.

So not only were we finding that patients with these external insulin pumps were getting better blood sugar control but the result was that those factors in their blood that caused heart disease, stroke, kidney failure and all the other complications of diabetes, were being dramatically improved by getting a pump that approximates the normal delivery of a pancreas.

[Slide.]

This slide shows what we developed. It's called PIMS. And on the left side is what's the patient's equipment; on the right side is the physician's equipment. The key piece is called the IPIP, Implantable Programmable Infusion Pump, that gets implanted under the skin of the abdomen, it takes half an hour and can be done under a local, we've done 10 of these at Johns Hopkins Hospital and eight of them at the University of California at Irvine.

The patient also has a simple hand programmer where he can call up the type of insulin that he needs to accommodate certain meals that he ate.

The physician's equipment consists of a personal computer designed to tell him what's happening with the patient and he can even speak to the patient over the telephone, with data, to put new prescriptions for insulin into the patient's abdomen, into the computer by telephone, and read out how the patient is getting his insulin.

[Slide.]

This is an example of how a patient with the device in the abdomen would ask for insulin to correspond to this lunch that she's about to have.

In the next slide—

[Slide.]

—this same person is shown as she would be in her home putting an antenna over her abdomen so she can communicate with her physician remotely and have new prescriptions put in and read out how she's doing with her diabetes.

Next slide, please.

[Slide.]

The key to it—like your watch, but even more elegantly—is microchips. This particular one is one that's used in our insulin pump. And where, when I first started working at Johns Hopkins 30 years ago, we had a computer that occupied a room the size of this room, and now that same capability is in a third of a cubic inch inside Dr. Pietrow's abdomen.

And the key to it is this technology evolved from NASA's space program in which we now get 10,000 transistors and 30,000 interconnecting wires on a single chip that's a quarter-inch in diameter.

Next slide, please.

[Slide.]

Here we see what one of those chips looks like magnified 100 times. If we move this like that—(Indicating)—you can see that, one mil, that is one 1000th of an inch, one-third the thickness of a piece of paper, and here you see in that dimension about six wires.

So we can see that we have now evolved the technology—and all these things, by the way, these are all kinds of chips here. These are different transistors that make up and gates, or gates and all the other wonderful magic of computer machinery.

Next, please.

[Slide.]

When it's all assembled, here is the top of our device—and I have one over here—(Displaying device.)

And this is the chart on the wall for everyone to see. You can see it's about three inches in diameter, it has eight chips with about 100,000 transistors on it and 300,000 interconnects. And this is what it looks like assembled.

[Slide.]

Here is the mechanical device. Again from the space program—this was done by the Parker Hannifin Company Aerospace Group, who took what they learned about doing space shuttle and putting a valve to land on the Mars surface and put it into a tiny pump. This complicated thing you see on the screen is in fact three-tenths of an inch high and four-tenths of an inch across and gives the accurate pumping of insulin from the reservoir into the patient.

[Slide.]

Well here's our first patient; they don't trust us with live people at first. And this patient is being programmed for his daily injection of insulin—now dogs eat only once a day, so that their need is different—

[Slide.]

But we can program his implant.

And here, on the 23rd of May, 1982, was the first actual measurement of drug flow into a living body sent out by telemetry, just as the space shuttle sends telemetry back to earth, so we have telemetry that sends the use of insulin back to the physician to analyze how well it's being done.

Next, please.

[Slide.]

Well how good did the dog do? This is plasma glucose, which is blood sugar, and this shows that between the PM measurement and AM measurements of this dog, it was between 450 units of blood sugar and down to 30; normal is about 100. So we see that this dog, before the dog had a pump, had this type of wide excursion of blood sugar that we measured.

[Slide.]

In the next slide, we show what happens when we put in the pump:

The first day it was down to 300; by the end of the week it was down to 150—

[Slide.]

And by the end of two weeks this dog was down to normal ranges of blood sugar. So we knew after we had done about 10 of these over three years we were ready to try it in a human subject.

Well the first subject was Dr. Piotrow, who is right next to me. I met him first just before the operating room and he was more nervous then than he is now, I believe, having had it working in him for 2-1/2 years and we found a very intriguing thing about Jack, he acted just like the dog.

[Laughter.]

Mr. FISCHELL. His blood sugar was running 200 to 300. Remember the first day with the dog, that looks just like Jack. But after 17 days, just like our dog also, he was down into normal ranges of blood sugar, which is just what the diabetic hopes for by the application of this technology.

[Slide.]

Finally, this is a summary of our first ten patients at Johns Hopkins. This is their mean blood glucose, how good is their blood sugar. And we see in every case where it was high it was made dramatically lower, to normal, and, in those which began by being near normal, stayed that way.

But I want you to know that this chart is not comparing injection therapy with our pump, but comparing the finest external pump therapy—which is much better than injection, a very fine therapy—with what this pump can do and we see remarkable improvement by the application of space technology in this regard.

[Slide.]

In the last slide I have something that might be surprising to you, ladies and gentlemen, which is the cost of diabetes in the United States in the year 1987: $20.37 billion.

Now we think, and studies have been made at the University of Minnesota to show that the application of these drug pumps can change the complications of diabetes to dramatically decrease the cost long-term in the treatment of diabetes in America.

The problem is there is not an easy mechanism to pay for it. The insurance companies do not reimburse for this, even if it is approved for commercial sale by the FDA, because the insurance companies, to help their budgets, fight every new technology development and try to resist reimbursement which would encourage it.

This is a problem that I'm sure you people, with your contacts, can do a lot more about than I can, but it is the single biggest problem in preventing this technology from being developed in America by the small company that's doing it.

Because if they can't get reimbursement for their product—and they cannot—it is very difficult for them to promote that product for America, which will not only help us economically, be a dramatic help in exports, but of course would have extraordinary benefits for those patients who need and would dramatically benefit by this application of space technology.

I would now like to turn over the discussion to Dr. Piotrow and give you an opportunity to ask questions, preferably when Jack is done speaking.

[The prepared statement of Mr. Fischell follows.]

TESTIMONY OF
ROBERT E. FISCHELL
BEFORE THE HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
APRIL 13, 1989

Mr. Chairman, members of the committee, ladies and gentlemen: The Space Act which resulted in NASA's creation conceived of the application of space technology spin offs to directly benefit mankind. This morning I will describe to you an excellent example of one such transfer of space technology into medicine. From the outer space of earth satellites to the inner space of diabetic patients in whom we have now implanted computer controlled, programmable insulin pumps that mimic the human pancreas.

INTRODUCTION

These are exciting times for the biomedical engineer whose career path has led him to utilize space technology in the development of microcomputer-controlled devices that operate within the human body. The invention of the transistor in 1947 made possible the first electronic device to be implanted in a human subject, an artificial cardiac pacemaker,[1] and also made possible the first electronic systems for spacecraft. Those technological breakthroughs resulted from three specific characteristics of the transistor as compared to the vacuum tube, namely: (a) an order-of-magnitude smaller size, (b) two orders-of-magnitude less electric power consumption, and (c) an indefinitely long life. Where the transistor made possible spacecraft and electronic medical implants, in the coming decade the integrated circuit chip will extend by orders of magnitude the capabilities of such devices. The results will be a revolution in the treatment of human disorders that until now have been treated only poorly, if at all, and a dramatically increased capability for space vehicles.

An early application of microcomputers implanted in humans is the Programmable Implantable Medication System (PIMS), which has been developed at The Johns Hopkins University Applied Physics Laboratory (APL) under sponsorship of NASA/Goddard Space Flight Center. This device has characteristics very similar to those of an orbiting spacecraft. The major similarities are that PIMS includes a command system; a telemetry system; a miniature, long-life power system; and very-large-scale integrated circuit chips. It also has been designed and fabricated using space reliability and quality assurance techniques. All these characteristics were a direct result of the transfer of space technology.

The implantation of PIMS in several diabetic humans occurred at the end of 1986. Next, implantable microcomputers may be used for the closed-loop control of diseases such as hypertension; that is, the blood pressure would be sensed in vivo and an antihypertensive medication released according to a programmed algorithm. This would be the first of a new generation of instruments that mimic the function of the human body by sensing a physiologic parameter and making an appropriate response just as the body would do if it were functioning normally.

OUTER SPACE TO INNER SPACE

There is an extraordinary degree of similarity between spacecraft operating in outer space and electronic medical implants operating within the inner space of the human body. The major similarities occur in the command system, the telemetry system, the power system, microminiaturization, and reliability.

Command System

The first spacecraft (Sputnik, Explorer I) orbited the earth and merely emanated a steady radio-frequency output. The first electronic medical implant was a heart pacemaker whose output pulse rate was fixed. As space and implant technology developed, both spacecraft and implants required more flexibility and capability. Thus, command systems were developed that allow a spacecraft's mode of operation to be altered in orbit by a radio signal from a ground station. For example, command functions used on APL (and other) spacecraft turn various subsystems on or off, change the level of the radio-frequency output of a transmitter, replace a failed subsystem, change a parameter of an orbiting experiment, etc. Implanted electronic devices use command systems that operate from a radio signal originating in a doctor's console that is, of course, exterior to the patient. Control commands in modern pacemakers change the stimulation pulse rate, pulse voltage, or pulse width; enable or disable an electrical signal from the atrium; and adjust the sensitivity for an electrical signal from the ventricle. The PIMS command system is used to change basal delivery rate, to turn the device on and off, and to set limits on medication usage. A spacecraft command system permits the spacecraft to adapt to its environment and to its specific condition, thus maximizing its use for a variety of purposes. A command system for an implant allows it to adapt to the patient's changing needs.

Telemetry System

Telemetry involves the transmission of data from a remote location. In the case of a spacecraft, telemetry is accomplished via modulated radio waves sent down to ground receiving stations. Typical measurements from a spacecraft might be the confirmation of parameters that have been commanded into it, the battery voltage, and particle densities, both in real time and as stored data. Similarly, typical implant telemetered data might be the confirmation of the parameters that have been commanded into it, the battery voltage, and the rate of medication infusion, both in real time and as stored data.

Power System

Power systems for spacecraft and implants must be small and long-lived. Both spacecraft and implant systems have used rechargeable nickel-cadmium cells to store energy and to operate the system between recharges. More recently, the power demands of implantable medical electronic devices have become so small that a single, AA size, lithium primary cell can operate some devices without recharging for more than ten years. Such is the case with the PIMS implant.

Microminiaturization

Until the age of the space shuttle with its huge payload capability, it was a struggle for spacecraft designers to meet payload size and weight limitations. Thus, an extraordinary effort was made to reduce size and weight while, at the same time, striving to increase operating capabilities; therefore, microminiaturization of electronics became commonplace in spacecraft design. The ultimate striving for size reduction has been, and still is, a goal for the design of implantable electronic medical devices. At the same time, increased capability has also been demanded. The first pacemaker (circa 1960)[1] used only two transistors, measured 3 inches in diameter by 1 inch thick, and weighed approximately 250 grams. Modern multiprogrammable pacemakers[2] contain the equivalent of 100,000 transistors yet have one-tenth the volume and one-fifth the weight of the first pacemaker. Thus, while demonstrating enormously better performance, their electronics has been so miniaturized that they are now being comfortably implanted even in newborn babies.

Reliability

An often overlooked and sometimes unglamorous aspect of both spacecraft and implants is reliability. The failure of a spacecraft results in the loss of an extraordinarily expensive machine; therefore, a whole discipline of reliability was created to ensure long life in orbit. Early spacecraft frequently failed during launch or after a few days in orbit, but the careful application of reliability engineering has resulted in extended life. An excellent example is APL's Transit Navigation Satellites, whose lifetimes in orbit are now well beyond a decade.[3] The first pacemaker failed within 12 hours of human implantation. In early 1970, many pacemakers ceased to function in less than 2 years because of component failures. By applying reliability and quality assurance techniques derived from space technology to the design of the Johns Hopkins rechargeable pacemaker, hundreds of these devices are still functioning after more than 10 years of continuous operation within humans.[4,5] The lithium-battery-powered PIMS implant should demonstrate reliabilities that also will ensure a 10-year life in vivo.

DEVELOPMENT OF IMPLANTABLE MICROCOMPUTERS

The microelectronic chip has revolutionized the design of spacecraft and hand-held computers to mention just two things from a long list. In only a few years the slide rule has become an antique. Although it will take longer, the chip as part of an implantable microcomputer system will revolutionize the treatment of a variety of human dysfunctions and will make the single transistor essentially obsolete.

The increased capability with time of integrated circuits (i.e., chips) is shown in Fig. 1. From the figure, we see that in 1959 there was only a single component on a single piece (or chip) of silicon. By 1982, chips were being made with 450,000 components. Although the number of components per chip may grow in the late 1980s to over one million, even today the chips can pro-

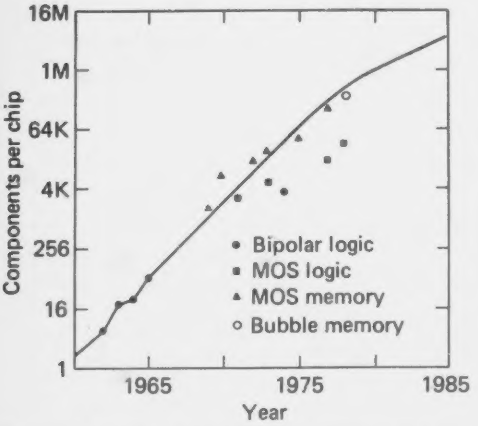


Figure 1—Increase in the number of components on a chip since 1959.

vide extraordinary capability for implantable electronic devices.

Listed below are the parts of an implantable microcomputer. They are typically, but not always, on separate chips.

1. The universal asynchronous receiver/transmitter is the means for interfacing the computer with the outside world; i.e., it is the input/output interface of the microcomputer.
2. The microprocessor serves as the central processing unit of the microcomputer.
3. The read-only memory is hard-wired (i.e., fixed) circuitry that provides specific functionality for the microcomputer. Because read-only memories are custom-made devices, a programmable read-only memory, a read-only memory erasable by ultraviolet light, or an electrically erasable, programmable read-only memory is frequently used in the early stage of microcomputer development because it can be readily reprogrammed, as is often required during developmental stages.
4. The random-access memory (RAM) serves as a recorder of any digitally encoded information, e.g., programming instructions or the hourly use of medication.
5. Universal arrays are semicustom logic chips that can be procured at reasonable cost ($10,000 for the first 100 chips) and in a reasonably short time (10 weeks). They provide a variety of AND gates, OR gates, etc. required for a particular computer logic.
6. Custom very-large-scale integrated circuits offer the possibility of ten times the number of components per chip compared to universal arrays, but their cost ($100,000 for the first 100 chips) and delivery time (6 to 12 months) preclude their use during developmental stages.

THE 1987 STATE OF THE ART OF IMPLANTABLE MICROCOMPUTER SYSTEMS

Not many computer-controlled implantable medication systems exist. One, the Programmable Implantable Medication System (PIMS), has been developed at APL through extensive use of space technology. Figure 2 shows the various parts of the system. At the left is equipment used by the patient, and at the right is equipment used by the physician. The implantable portion of PIMS, which contains the microcomputer subsystem, is called the Implantable Programmable Infusion Pump (IPIP).

The patient is provided with a hand-held device called a Patient's Programming Unit by which he can initiate self-medication from the IPIP within the constraints programmed into the IPIP by the physician. The main portion of the Medication Programming System is a computer terminal that is used for programming the IPIP. The device for refilling the IPIP is called the Medication Injection Unit. The last major portion of PIMS is a Telephone Communication System, by means of which the patient at a location remote from the Medication Programming System can have his IPIP reprogrammed with a new prescription or can have stored telemetry data in the IPIP read out and displayed by the Medication Programming System.

The potential advantages of PIMS or other implantable drug delivery systems are as follows:

1. A precise medication rate is available. (a) The medication level can be maintained within a very narrow therapeutic range. (b) A medication level can be maintained that is at a minimum level within a broad therapeutic range. Thus, the desired physiological effect can be obtained while significantly reducing overdosage. This factor could decrease the buildup of tolerance and side effects.
2. Perfect compliance can be achieved. The physician can write a prescription into the electronics of the implanted device and medication will be delivered at that prescribed rate without requiring patient compliance.
3. Medication can be delivered with any desired time profile or periodicity.
4. Accidental or deliberate overdose is prevented because the implanted device can be built with programmed limits that neither the patient nor the physician can violate.

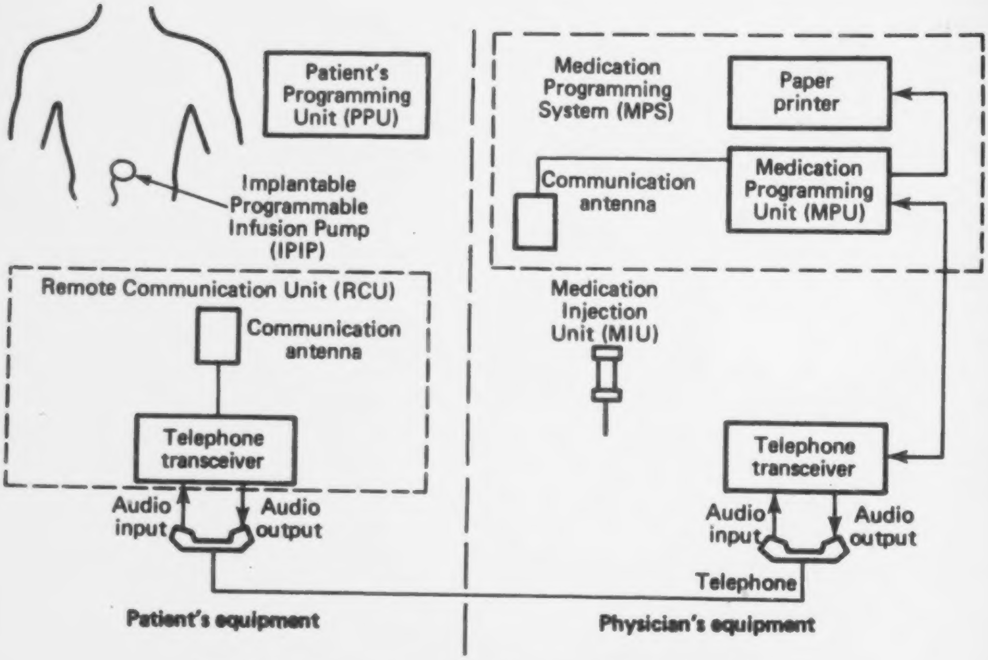

Patient's Programming Unit (PPU)
Implantable Programmable Infusion Pump (IPIP)
Remote Communication Unit (RCU)
Communication antenna
Telephone transceiver
Audio input
Audio output
Patient's equipment
Medication Programming System (MPS)
Paper printer
Communication antenna
Medication Programming Unit (MPU)
Medication Injection Unit (MIU)
Telephone transceiver
Audio input
Audio output
Telephone
Physician's equipment

Figure 2—The Programmable Implantable Medication System (PIMS).

5. Decreased use of medication is possible; for example, if a medication is more effectively delivered at a particular time of day, that can be accomplished by PIMS.
6. More appropriate medications can be used for the treatment of specific diseases. For example, if heparin therapy is more advantageous in the treatment of thrombotic disease compared to another drug substance such as warfarin, then PIMS can be used to deliver intravenous heparin.
7. Closely related to the previous advantage is that medications that would normally require the patient to be hospitalized could be safely given on an outpatient basis.
8. By placing the tip of the PIMS outflow catheter at an appropriate site within the body, medications can be delivered within a more confined boundary. Thus, one can enhance the action on the organ or cells that require the medication while decreasing the concentration of medications elsewhere in the body.
9. The physician can use PIMS to determine the precise medication level used by the patient on an hour-by-hour or daily basis.
10. An implanted system with a physiological sensor (not yet available with PIMS) can regulate medication delivery to exactly suit the patient's needs.
11. An implanted system can provide an alarm detectable by the patient when the desired physiological effect is not being achieved or when the device's functioning deviates from nominal.

The IPIP is disk shaped, with a diameter of 8.1 centimeters, a thickness at its center of 1.8 centimeters, a thickness at its edge of 1.3 centimeters, and a weight of 171 grams. The IPIP can be programmed for a constant or a variable basal infusion of medication with a repetitive period of from 1 hour to 60 days. By far the most frequently used basal period is 24 hours. A period of 28 days is available, particularly for the infusion of sex hormones to mimic the female cycle. The Medication Programming System can be used to program six different supplemental infusion profiles that the IPIP can deliver, when such delivery is initiated by the Patient's Programming Unit. The latter unit can also turn off the IPIP for 1 hour at the patient's request, countermand a prior command of the unit, or change the basal infusion rate to either half or full basal.

Figure 3 is a photograph of the IPIP with its outer cover removed to show the microcomputer electronics. At the center is the refill port. A hypodermic needle is placed through the skin and then through this port (which has a silicon rubber septum), for access to the IPIP reservoir. The chips (shown in ceramic chip carriers) are the microcircuits that make up the microcomputer controlling the IPIP. Toward the lower right of the photograph are two circular metal parts; the smaller is the solenoid pump and the larger is the fluid-flow-smoothing network. The object of the fluid-smoothing network is to take the pulsatile output of the pump and smooth it so that the outflow simulates the flow of hormones from an endocrine gland.

Figure 4 is a block diagram of the IPIP. At the center is the fluid-handling system, to the right is the command system, and to the left are the power and telemetry

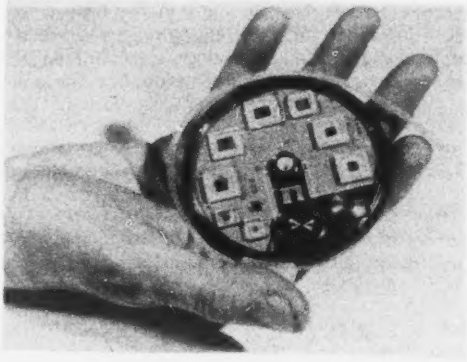


Figure 3—The Implantable Programmable Infusion Pump.

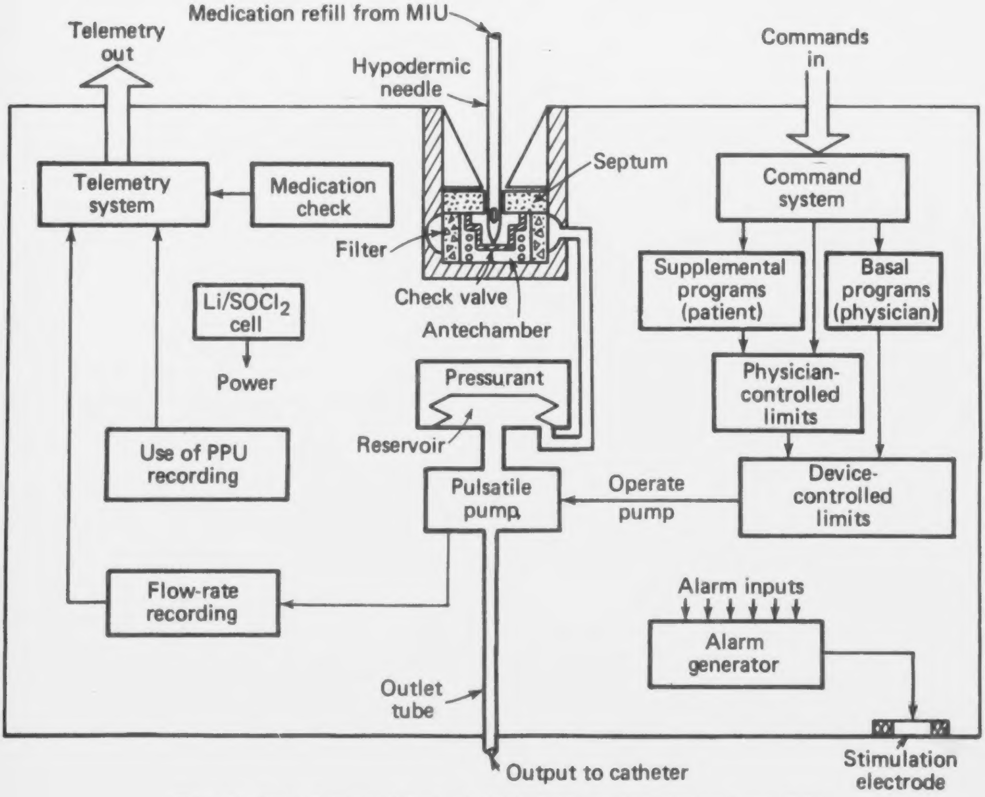

Medication refill from MIU
Telemetry out
Hypodermic needle
Commands in
Septum
Telemetry system
Medication check
Command system
Filter
Supplemental programs (patient)
Basal programs (physician)
Li/SOCl₂ cell
Check valve
Antechamber
Power
Pressurant
Physician-controlled limits
Reservoir
Use of PPU recording
Pulsatile pump
Operate pump
Device-controlled limits
Flow-rate recording
Alarm inputs
Alarm generator
Outlet tube
Output to catheter
Stimulation electrode

Figure 4—Block diagram of the Implantable Programmable Infusion Pump (IPIP).

systems. A noncoring (hole in the side) hypodermic needle is inserted through the skin, through a self-sealing septum, and into an antechamber, to permit filling the 10-milliliter reservoir with medication. The pressurant in back of the reservoir is a vapor/liquid system of Freon 113®, which maintains a constant negative pressure of −4 pounds per square inch (gauge). When the reservoir is filled, the Freon changes from mostly vapor to nearly entirely liquid; as the reservoir is emptied, the reverse is true. A negative pressure is always maintained. This technique was taken directly from rockets that use high-vapor-pressure liquid/vapor pressurants to expel monopropellants, rocket fuel, or oxidizers.

If there is a leak in the IPIP, body fluids will leak into the IPIP and no medication will be forced out. The pulsatile pump sends 2-microliter pulses of fluid into the flow-shaping network (see also Fig. 4), which smooths the flow out of the IPIP.

The command system operates by receiving commands from the Medication Programming System or the Patient's Programming Unit. Satellites cannot function properly if inadvertent commands change their operating state. Likewise, "phantom commands"[6] would be disastrous for implantable devices. That possibility is precluded by the "double handshake" secure command link shown in Fig. 5. From the external Medication Programming System or the Patient's Programming Unit, a 12-bit command is sent to the IPIP, where it is stored in memory. The data are then sent by telemetry back to the original source, where a bit-by-bit correlation is carried out. If all bits check out correctly, an "Execute" command is sent that allows the IPIP to carry out the command that has already been put in memory and therefore, since it was checked, is correct. This technique, which precludes the possibility of phantom commands, was a direct transfer of the technology for the Small Astronomy Satellite command system designed and built at APL.

Referring again to Fig. 4, by means of the command system, the patient uses his Patient Programming Unit to request supplemental medication. Also, the physician can program basal programs with the Medication Programming System. There are limits, controlled by the physician, on the amount of supplemental medication that the patient can request. There are also device-controlled limits that prevent the physician from prescribing too much medication.

To the right in Fig. 4 is the alarm system, consisting of many inputs to an alarm generator that, in turn, can alert the patient by means of a subcutaneous electrical stimulation, or "tickle." Typical reasons for alarms are:

1. Only a limited amount of medication is left in the reservoir.
2. Medication is leaking into the electronics chamber.
3. A basal program has inadvertently been changed.

On the left side of Fig. 4 is the telemetry system. Probably its most important aspect is its ability to recall the hour-by-hour medication flow out of the IPIP. An example of such measured data is shown in Fig. 6. These

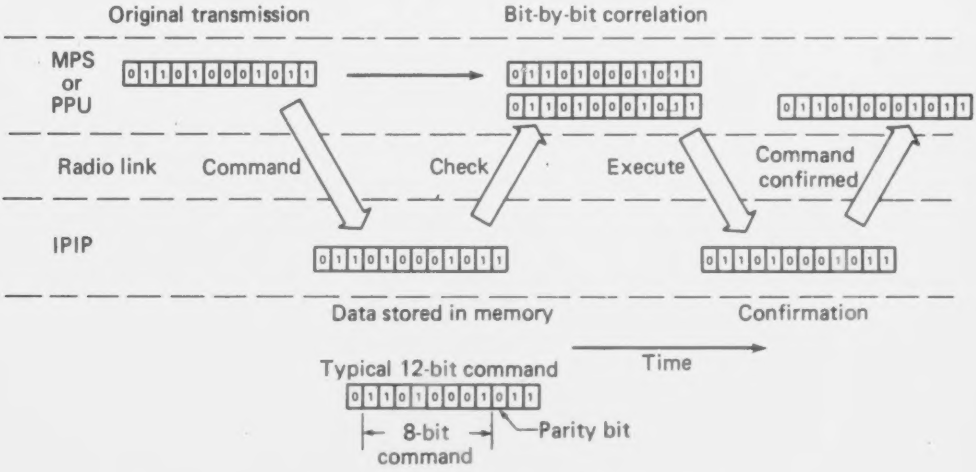


Figure 5—"Double handshake" signal format for secure communication.

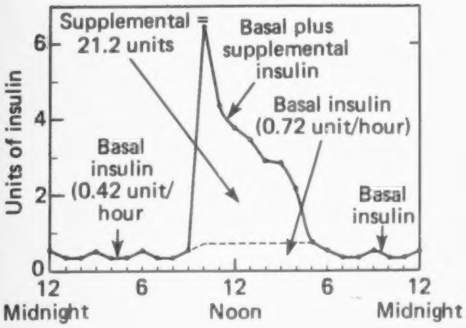


Figure 6—Telemetered measurement of insulin infusion on May 23, 1982.

data were sent from an IPIP implanted in a laboratory dog made diabetic by the removal of its pancreas. The data were recovered several days after the actual day of insulin infusion, which in this case was on May 23, 1982.

The last block in Fig. 4 is the lithium thionyl chloride ($Li/SOCl_2$) cell. That cell, especially made for IPIP, can operate the first IPIPs for more than 6 years without recharging. New versions of the IPIP already being fabricated will have a greater than 10-year implant life.

Figure 7 shows how a patient might use a Patient Programming Unit to self-medicate with insulin prior to eating a meal.

Figure 8 shows how a patient might have a new prescription "written" into her microcomputer without the IPIP by means of the Telephone Communication System. The patient could also have the stored data on medication usage telemetered back to the physician by telephone from her home.

MEDICAL APPLICATIONS OF PIMS

The microcomputer-controlled delivery of medication by PIMS will provide improved treatment for several diseases.

Diabetes

The application of PIMS to diabetes by the controlled release of insulin is one obvious medication application.[7] Preliminary data show that the continuous release of insulin from a pump, with supplemental doses at mealtime, provides dramatically better control of blood sugar. Furthermore, there have been reports of the reversal of diabetic retinopathy[8] and of other improvements in the diabetic condition when the pump release of insulin has been used.

The first human application of PIMS was in a diabetic patient at the Johns Hopkins Hospital on November 10, 1986. The IPIP used the intraperitoneal delivery route. Figure 9 shows the initial basal program commanded into the implanted portion of PIMS (the IPIP). Each pulse delivers a volume of 2 microliters, which for U400 insulin provides 0.8 unit per pulse. The increased basal dosage between 3:00 AM and 5:00 AM was to counter the so-called "dawn effect"; i.e., increased blood

Figure 7—Demonstration of a patient self-medicating with insulin prior to eating.

Figure 8—Demonstration of a patient having a prescription "written" into her IPIP and the data telemetered to the physician by telephone.

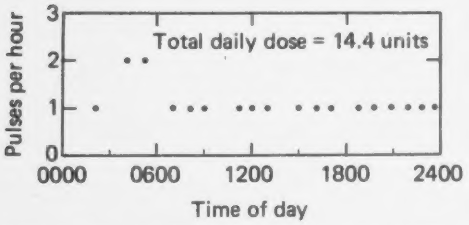


Figure 9—Basal insulin infusion schedule for first patient.

sugars occur in the early hours if more insulin is not provided.

Figure 10 shows how the first implanted IPIP responds to command No. 5 of the Patient Programming Unit. The insulin is delivered with a double exponential curve (first increasing then decreasing) that mimics the action of a normal pancreas. The maximum delivery rate is 1.0 unit per minute, the delivery time is 90 minutes, and the total integrated insulin dose for command No. 5 is 12 units. The IPIP reservoir contains approximately 12 milliliters of medication. For a patient using 50 units per day of insulin, the reservoir would typically be refilled four times each year.

Figure 11 shows the first patient's blood sugar on days 1, 2, 17, and 18. As with the case of laboratory animals, blood sugars immediately after surgical implant are quite high. However, by day 17, the mean blood sugars are within the normal range.

The results of blood sugar measurements in the first patient 30 days after implant are shown in Fig. 12. At 8:00 PM on December 9, the patient ate a 900-calorie meal and inadvertently failed to request supplemental insulin. By 10:00 PM, his blood sugar rose to nearly 400 milligrams per deciliter. He then immediately began a course of supplemental insulin to lower his blood sugar. This inadvertent omission of supplemental insulin indicates just how very sensitive such Type I diabetic patients are to lack of proper insulin infusion. By the next day, the patient's mean blood-sugar level was just at the center of the normal range. Even though the patient did reach nearly 400 milligrams per deciliter for a short time, it is believed that cellular damage is a result of the time integral of the blood glucose and, therefore, a short duration at a high blood-sugar level does not have a perceptible deleterious effect.

Relief of Chronic Pain

Another important PIMS application is for the spinal infusion of morphine for the treatment of chronic pain. Prior results with nonprogrammable, implantable medication delivery systems[9] have been shown to provide quite excellent pain relief without a great deal of tolerance buildup by the patient. The advantage of PIMS

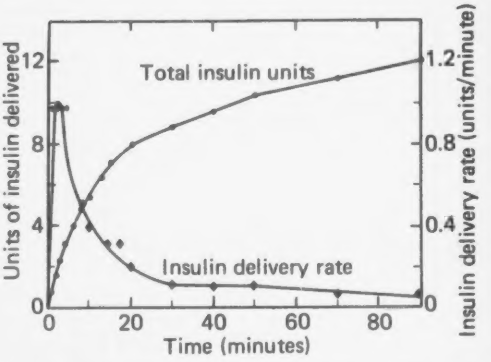


Figure 10—Supplemental insulin delivery for PPU command No. 5. Total number of units, 12.

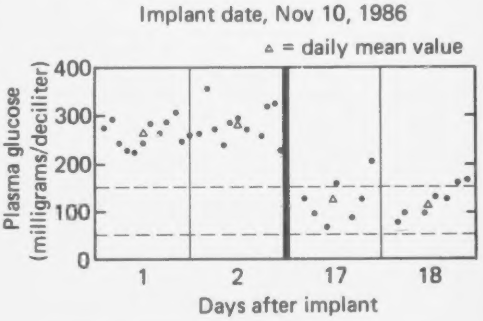


Figure 11—PIMS results in first human subject.

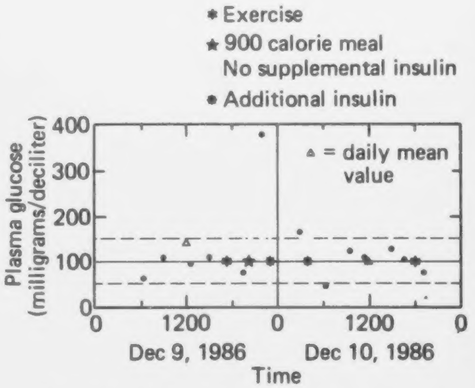


Figure 12—PIMS results 30 days after implant.

over nonprogrammable implants is that the patient can elect (by means of the Patient Programming Unit) to have the morphine delivered only when he has pain. Thus, pain relief would be maximized and tolerance buildup would be minimized.

Diseases of the Central Nervous System

Several diseases of the central nervous system might ideally be treated by PIMS using intrathecal infusion (infusion into the cerebrospinal fluid). Infusion directly into the cerebrospinal fluid bypasses the blood-brain barrier so that the medication can be delivered directly to the region where it is needed. Some diseases, discussed below, might ideally be treated by placing the IPIP subcutaneously in the abdomen while placing the catheter tip beneath the dura mater of the spine so that infusion is made directly into the cerebrospinal fluid.

Amyotrophic Lateral Sclerosis (*ALS*). From data obtained from Dr. T. Munsat of the New England Medical Center,[10] spinal infusion of the hormone TRH appears to slow the rate at which ALS patients lose their muscular strength. It is believed that TRH has a trophic effect on the deteriorating cells in the spinal cord. To date, these patients have used nonprogrammable pumps with a uniform rate of infusion. The pulsatile administration of TRH may offer some further advantage in that large boluses can be administered, achieving very high TRH concentrations followed by a clearance of the drug so that the cells will "recover" to their normal state.

Parkinson's Disease. Parkinson's disease is a result of the lack of the neurotransmitter dopamine within the brain. Although the oral administration of L-dopa is efficacious, especially in the earliest years after onset, the later stages of the disease are often poorly treated by this drug. Direct infusion of dopamine into the cerebrospinal fluid can have potentially great advantages in that the medication will be delivered to the site where it is needed with any desired time profile that may best control the manifestations of this disease.

Alzheimer's Disease. Only recently has there been any progress in the treatment of Alzheimer's Disease. Certain drugs (such as bethanechol) taken orally have been reported in the news media to improve the patient's mental acuity. If there is some medication that can be beneficial in the treatment of Alzheimer's Disease, it would undoubtedly be most effective if delivered into the cerebrospinal fluid so that it can reach the affected cells in the brain without passing through the blood-brain barrier. PIMS, with a catheter tip placed beneath the dura of the spine or actually within a ventricle of the brain, should be ideally suited for delivering such medication.

PRESENT STATUS OF PIMS

It has now been 2½ years since the first PIMS device was implanted at The Johns Hopkins Hospital beneath the abdominal skin of Dr. F. J. Potrow. Since that time, at Johns Hopkins and later at the University of California at Irvine (UCI), a total of 18 devices have been implanted in insulin dependent diabetic patients. Although there have been 2 catheter blockages in 2 patients at UCI, the sophisticated PIMS itself continues to perform close to perfectly in all 16 of the patients remaining in this original study. The extraordinary reliability for such a new and sophisticated implantable device is actually a reflection of the excellence of the space technology techniques used in its creation. The health and personal outlook of each of these patients has been certainly improved, sometimes dramatically, by the use of the NASA sponsored PIMS implant.

But when will this wonderful advance in medical technology become available for the 1½ million insulin dependent diabetics in the U.S.? What device will be available for the present 16 patients when their PIMS batteries cease to function starting approximately 2½ years from now? Although NASA invested $3M in the PIMS program, private industry has already invested at least three-fold that amount. Now, the PIMS licensee, MiniMed Technologies, Inc., a small biomedical device company from Sylmer, Ca., has to complete the development of the production version of PIMS and test an additional 100 units in order to obtain FDA approval for commercial sale. PIMS results to date indicate that FDA approval will be clearly warranted. However, the real problem is that there is no reimbursement from Medicare or any insurance company for these devices. The approval for commercial sale by the FDA is not of itself sufficient to allow third party reimbursement for PIMS and its associated implantation expense.

If this new technology was used to create a heart pacemaker, or a new dialysis machine, then all the associated expenses would be provided. However, since PIMS for diabetes represents a new therapeutic modality, *even after completion of its clinical trial and review and approval for commerical sale by the FDA*, only quite wealthy individuals will be able to affort the approximate $8,000 initial device cost – $2,000 more than a pacemaker.

The effect of this lack of reimbursement, is to put a damper and almost a complete stop on valuable but sophisticated medical technologies resulting from the transfer of space technology.

A recent study by the American Diabetes Association has shown that the cost to the U.S. for the care and treatment of diabetes is just over $20 billion a year. Another study published by the University of Minnesota shows that implantable pumps such as PIMS can, in the long term, dramatically reduce the cost of caring for diabetic patients. Furthermore, it has been shown that PIMS patients have a distinctly improved quality of life and have every reason to believe that the use of

PIMS will reduce diabetic complications such as blindness, early stroke and heart disease, loss of limbs, and the need to be put on kidney dialysis machines.

The major obstacle to the rapid expansion in the use of this wonderful new NASA technology is the unavailability of insurance coverage for the diabetic. Hopefully Congress could help in finding a workable solution to that problem which now is directly preventing this elegant inner space technology from being made available for all of mankind.

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STATEMENT OF DR. F. JACKSON PIOTROW, SCHOOL OF INTERNATIONAL SERVICES THE AMERICAN UNIVERSITY, TENLEY CAMPUS, WASHINGTON, D.C., PRESENTING THE PROGRAMMABLE, IMPLANTABLE, MEDICATION SYSTEM

Dr. PIOTROW. Good morning. Thank you, Mr. Chairman, and members of the Subcommittee.

My name is F. Jackson—Jack—Piotrow. I am lucky to be 57 years old. I am a Professor at American University, the School of International Service.

I guess the reason I am here this morning is not so much because I am afflicted with a chronic, really incurable disease but, more importantly, because I am the very enthusiastic beneficiary of one of the technology applications of NASA technology.

I have been a diabetic for almost 29 years, since April 1960. I am very fortunate that I was selected to be the first person to receive the PIMS, the Programmable Implantable Medication System and the associated pump. And I think as a result I am never going to give way to the temptation to think that advances in medical technology are inevitable and to be taken for granted.

I might, just for contrast, try to point out, to denote the difference between my life after PIMS and to say something about life before PIMS.

When I became a diabetic, my life really was saved by the application of insulin, insulin therapy. As Mr. Fischell has said and as all of you know, I'm sure, insulin is not a cure. It can prolong life; in my case, it saved life. It made it possible to try to make an approach to normal life but, really, normal, free life is not a prospect for most people.

Also I am a brittle diabetic, which means that under normal insulin conventional therapy my blood sugars would swing rather widely sometimes from high to low and back to high again. This imposes restrictions on one's lifestyle.

I might point out that very early in my career I was Foreign Policy Assistant for the late Senator Hubert Humphrey. And once, in 1962, there was a very critical debate on the question of Katanga, my job was to be on the Senate floor and, at just about the worst moment of that debate, I had to leave so I could have a meal to spare me from what otherwise would have been a very severe hypoglycemic incident, or insulin reaction. And there have been other occasions, much, much worse than that. And all diabetics, insulin-dependent diabetics, seem to experience them.

I think for this reason the scheduling restrictions, the need to coordinate meal times with the taking of insulin and so forth to know what you're doing and what you're measurements are at almost any particular time of the day, these can impose very overwhelming feelings on the diabetic. And the diabetic often feels done in by the disease, even though outwardly it looks as though he's living a normal life. There are constant inconveniences combined with health impairment or the threat of health impairment.

I would say that PIMS, when I received it 2-1/2 years ago, had made an extraordinary change for the better, in my life, in my feelings about things and in my effectiveness really on the job.

For one thing, say if I were out to dinner or at a restaurant, instead of having to undergo the embarrassment of excusing myself and going out to take an insulin injection, if I may, sir, I will rise and show you what can be done.

I am going to set the pump for command one and deliver it—(Demonstrating). The beep indicates that I just received an injection of 1.2 units of insulin, which would be delivered over a period of ten minutes.

So before the ten minutes gets much farther along—(Demonstrating)—I'll cancel it.

[Laughter.]

Dr. **Piotrow**. It's impossible to say what a difference this makes in one's normal living.

[The prepared statement of Dr. Piotrow follows.]

The Programmable Implantable Medication System
A Diabetic's Experience with NASA-Funded Technology

TESTIMONY

Subcommittee on Space, Science and Applications
Committee on Science, Space and Technology
U.S. House of Representatives

April 13, 1989

F. Jackson Piotrow, D.Phil.
Professor
School of International Service
The American University

Mr. Chairman and Members of the Subcommittee:

Thank you for inviting me to testify this morning concerning my experiences to date with the Programmable Implantable Medication System (PIMS), which features an implanted pump used in my case for the infusion of insulin. I was the first person to receive the pump, known as the Implantable Programmable Infusion Pump or IPIP. The device was implanted in a surgical procedure performed in November 1986, almost exactly two and a half years ago. It has worked perfectly ever since and has contributed to a marked change for the better in my control of diabetes and in my psychological adjustment to the disease. The other nine recipients of PIMS in the Baltimore-Washington area concur in my enthusiastic assessment of the device and the technology which produced it.

The pump rests under the skin on the lower left portion of my abdomen above the belt. It delivers a unique, highly concentrated form of insulin through a catheter inserted through the peritoneum into the abdominal cavity. Invented by Mr. Robert Fischell, the system was developed by a team of scientists and engineers under his direction at the Applied Physics Laboratory (APL) of the Johns Hopkins University. It was manufactured by the company now known as MiniMed Technologies in Sylmar, California. Dr. Christopher D. Saudek, Associate Professor at the Johns Hopkins School of Medicine and Director of the Johns Hopkins Hospital Diabetes Center, conducted clinical trials of the system over a period of four and a half years. Notable among the many contributions to the PIMS project by private firms in the United States and Europe were the development of the basic pump unit by the Parker Hannifin Corporation of Irvine, California, and the production by the Hoechst Corporation of Frankfurt, West Germany of a U-400 insulin which retains its stability for months at body temperature. None of this collective effort would have been possible, however, had it not been for the vision, the design capabilities, and the longterm financial support of the National Aeronautics and Space Administration.

My Life as a Diabetic

In this day and age it is tempting to take technological breakthroughs for granted. Given the overall advance of medical technology in my lifetime and the applications of that technology to previously intractable problems of physical and mental health, it would be understandable to look at PIMS the same way. Through some highlights of my history as a diabetic, however, I should like to indicate why the implanted pump has given me substantial benefits and also why one should not assume that progress of this kind will continue indefinitely.

I am now 57 years old. As my biography indicates, I am a professor at the School of International Service of The American

University in Washington, D.C. Prior to joining the AU faculty, my career included a brief stint as Foreign Service Officer and a year and a half as Assistant on Foreign Affairs to the late Senator Hubert H. Humphrey.

In 1960, just as I was starting what I hoped would be a career in the Foreign Service, I suddenly developed diabetes mellitus. Classic symptoms of the disease in the winter and spring of that year led to ketoacidosis, hospitalization, and lifesaving insulin therapy. From that time until now I have required some 45 to 55 units of insulin daily in order to survive and live a "normal" life. Yet a truly normal life was gone forever. Practical considerations of assignments overseas with uncertain medical care persuaded me to leave the Foreign Service and go into academic life.

There is no question that insulin deserves the credit for restoring me and countless other diabetics to productive life. At the same time, insulin forces all who receive it to follow a daily regimen of juggling diet, medication, exercise, and stress in order to function at a minimally acceptable level.

In 1960 when my condition was diagnosed, the control of diabetes meant that one had to boil steel needles and glass syringes, to give oneself usually one injection daily of longlasting insulin (or several injections of rapid-acting regular insulin), to go to one's physician for periodic blood glucose monitoring, to test one's urine for sugar and if necessary for ketones and acetone, to adhere to a diet regulating the ingestion of carbohydrates, to keep records, and to attempt to incorporate exercise into an already complicated lifestyle. At the same time one tried to live as others lived and to achieve both professional and personal goals.

Between 1960 and 1986 remarkable changes took place in the treatment of diabetes; each of them contributed to easier control and to improvements in the lives of diabetic patients. Among these changes were the development of disposable needles and syringes, the introduction of home blood glucose monitoring devices, better dietary programs, more flexible and effective varieties of insulin, and the prescription of multiple daily insulin injections for diabetics who wished to maintain "tight" control of the disease.

Nevertheless, progress in the handling of a chronic disease does not mean the end of the disease. Normal life for the diabetic was still a contradiction in terms. As a "brittle" diabetic, with sometimes wild swings in blood sugar from high to low and back again, I would face each day not knowing whether I would have an insulin "reaction" (hypoglycemia) while driving to the university or in the middle of a lecture or whether the need to urinate (caused by excessively high blood sugar) would force me to leave the room at an awkward moment during a meeting or, if was on a trip, to pull in at successive rest areas on the New Jersey Turnpike.

The timing of meals was a major restriction. When insulin is administered at specific times to provide round-the-clock coverage, the patient must be sure that he or she has food in the system to balance the peak periods of insulin activity. Conversely, one does not want to eat a meal when there is insufficient insulin in the system to cover it. These requirements impose constant scheduling demands on the diabetic. In my case it was hard for others around me to understand why--on a trip, for instance--I had to pull over and eat at a certain time. Or why a meeting would have to end or I would have to walk out just because it was lunchtime.

Once, when I was on Senator Humphrey's staff, I had to leave the Senate chamber at a critical moment in a debate on Katanga because further delaying lunch would have brought on a severe hypoglycemic reaction. In the early 1970s I nearly passed out on a ski slope because I had taken too much insulin and had eaten too little at lunch in relation to my blood sugar (which I was unable to test) and the strenuous activity of skiing. The members of the ski patrol who found me falling and trying to get up at the foot of the hill naturally assumed that I had had a bit too much of the local brew. Luckily, my wife realized what was happening and gave me needed sugar in the form of a Coke. On another occasion, while we were visiting friends near Philadelphia, I got up out of bed one morning and was in the process of chasing my two children around the yard while brandishing a hammer when my wife, despite fearing for her own safety, persuaded me to drink a glass of orange juice.

Episodes like these, ranging from the bizarre and the embarrassing to the potentially tragic, are the common subject of meetings and social get-togethers involving diabetics. Our conversations turn around the unremitting attention which is required in order to stay in relative control of the disease. The insulin-dependent diabetic always pays in some unpleasant form for mistakes in judgment, inattention to detail, or psychological denial and failure to face up to the condition. For this reason, many people feel overwhelmed by diabetes; it is a constant, unforgiving, demanding presence in their lives.

Difficult as the life of a diabetic may be at times, the disease should be kept in perspective. The well controlled diabetic certainly is not worse off than the paraplegic, the AIDS victim, the heart transplant candidate, or the cancer patient. For my part I am grateful to be alive and to be able to work and take recreation even if under restrictions. I am also thankful that thus far I have not acquired any of the complications associated with diabetes: diabetic retinopathy, kidney disease, cardiovascular and neurological problems, and--for women--risks of miscarriage and other problems associated with childbirth. The point is that although diabetes need not be fatal or permanently disabling, it is an abnormal condition which claims millions of victims in the United States and around the world. Untreated, or improperly treated, it can lead to severe impairment of health. For too many people in our own country it is still responsible for the degradation or loss of life. Many complications of the disease occur almost regardless of the patient's state of control; age of onset seems to be a major factor. Measured by the social costs of the disease alone (health expenditures, loss of working productivity, strains on the medical infrastructure), the disease is worthy of our best efforts of study and technology application.

PIMS: Effects of The Breakthrough

The Implantable Programmable Medication System has made it possible for its first recipients to live a freer, more normal life while at the same time demonstrating improved diabetic control. My own experience is consistent with this statement.

In 1984 Dr. Leonard A. Wisneski, my personal physician and endocrinologist, recommended that I investigate the possibility of acquiring one of the externally worn infusion pumps which recently had come onto the market. Dr. Angelike Georgopoulos of the Johns Hopkins Medical School then introduced me to the MiniMed infusion pump. Worn on the belt or carried in a pocket, the MiniMed pump is connected by plastic tubing to a needle which in turn is inserted into the skin and taped to the body. Needle, tubing, and insulin should be changed every two days. Although the pump is a marked advance, in terms of controlling blood sugars, over conventional methods of insulin delivery, it has its disadvantages: wearing and changing the tubing is inconvenient; the same is true of disconnecting or clamping off the infusion set when taking exercise or showers; the wearer experiences occasional discomfort from the needle; infusion sets can be blocked and insulin not delivered; and in my case, hypertrophy developed from overuse of a single area of the stomach for needle insertion.

The principal advantage of the external pump was an immediate tightening of my control of diabetes. Yet better things were to come.

In 1986 I learned that Dr. Saudek of Johns Hopkins was ready to proceed with human trials of the system known as PIMS. When I called Dr. Georgopoulos to express interest, she recommended me for inclusion in the program. That summer I spoke with Dr. Saudek and enrolled in the program. Starting in July, Dr. Saudek and his clinical staff monitored me for insulin usage, blood glucose results, diabetic complications, and overall physical condition. In November I entered the Johns Hopkins Hospital research wing, and on November 10 Dr. Henry Pitt performed the surgery that made me the first patient to receive the PIMS implanted infusion pump.

Once I had recovered from surgery, PIMS established excellent control of my diabetes. It has remained excellent for the 29 months that have now elapsed since the implant. Although my purpose here today is not to transmit data, I should mention that with PIMS only 10-15 percent of my blood sugar tests (I normally do six tests daily) are out of range, that is, lower than 60 mg/dL and higher than 200 mg/dL. Weeks go by without highs in the 300's or above; when high readings occur, they are swiftly corrected with painless, unobtrusive administrations of small amounts of insulin by means of the pump's manual controls. Although I still get low readings from time to time, episodes of extreme, traumatic hypoglycemia seem to be things of the past. The standard deviation of my blood glucose test results is narrower than before the implant. Average blood glucose values are in the 120s or 130s, and my hemoglobin A_1C results are well in the normal range.

In media interviews since the surgery, I have frequently stated that PIMS has changed my life--for the better. My fellow patients in the Johns Hopkins part of the experiment subscribe to this statement. Preparing for this hearing, I spoke by telephone to as many of them as I could reach late one afternoon. I asked them three questions: (1) If you had the choice of staying with PIMS or going back either to the external pump or conventional injections, would you revert to the system you had before? (2) If you prefer to stay with PIMS, please state why. (3) Is there anything about PIMS that you do not like?

I received a strikingly uniform set of answers. None of the four patients I talked with, including three men and one woman, preferred under any conceivable circumstances to abandon PIMS and return to the status quo ante. Most of them would go back to the external pump only if the IPIP had to be explanted or if the PIMS program came to an end. If this happened, they would reluctantly return to the external pump. My fellow patients unanimously like PIMS because of the "freedom" it gives them. For the first time since becoming diabetic, PIMS patients feel that they are in charge of their disease, not vice versa. They also have high hopes that the better control achieved through PIMS will reduce their vulnerability to other organic complications.

When I asked what they did NOT like about PIMS, my fellow patients had to grope for answers. One person, a thin young man, said he thought his implanted pump was rather more prominent than he liked when he wore a swim suit. Others mentioned the need, despite the automatic features of the system, to continue home blood glucose monitoring. Nevertheless, they would gladly continue the blood testing as long as no true "closed loop" system existed. They felt the same way about going to Johns Hopkins Hospital every two months for refills of the pump's insulin reservoir; this was a small price to pay for the privilege of dispensing with multiple daily injections.

I draw the following conclusion from this small sampling of opinion: whatever drawbacks PIMS might have, they are insignificant compared with the problems inherent in other methods of treatment and compared with the real benefits which the system provides. Naturally I wholeheartedly concur with this point of view.

The Future: Areas of Concern

Before entering the PIMS program, each candidate for an implanted pump signed a consent form acknowledging that the maximum duration of the program was three years. I am rapidly approaching that mark, and as things stand now I will be the first person to reach the three-year threshold. All of us are concerned that the program might come to a halt with dire consequences for the freedom and the health benefits which we have enjoyed through our participation in PIMS. These are not idle concerns. We signed the consent form with our eyes open, but we are not prepared psychologically to give up PIMS when the program is clearly successful both technologically and medically. In fact, we would feel unfairly used if the worst-case scenario--compulsory removal of the pump--were to come to pass.

We are assured that no one contemplates extraction of the pump just because an arbitrary time limit has been reached. At the same time there is no question that the PIMS program is over. Although PIMS is superb from an engineering standpoint, it is also expensive to produce, and the company is unlikely to recover its investment. No more federal money is going into the program to sustain it, even though the program is effective and well received.

In the patients' view, the problems and uncertainties surrounding PIMS underscore an important issue in the development and application of medical technology. At its most basic level, the question is whether ethically a technological innovation should be tested on patients desperate for help and then withdrawn after its success has been demonstrated. By the same token few would question the right of the firm to avoid expensive, nonremunerative, unreimbursed, longterm development costs for a project which will not make it in the marketplace.

The patients in the PIMS experiment join me in expressing the hope that Members of Congress will look at this moral and economic dilemma from the perspective of what is best for the sustained development of innovative medical technology. A not insignificant part of the public interest is at stake. In that spirit I fully associate myself with the remarks of Mr. Fischell.

Mr. **Nelson**. As I understand it, you are an avid tennis player. This has allowed you to have a more normal life as a tennis player?

Dr. **Piotrow**. My opponents would not necessarily agree with you—

[Laughter.]

Dr. **Piotrow**.—but I feel, yes, sir. Yes, sir.

Mr. **Nelson**. Mr. Fischell, I understand that you developed this device on your own on a two-week vacation?

Mr. **Fischell**. That's right. I was—When I used to go away for vacations and still do with the family down to the Caribbean, I would always take a project along to invent something new. And it was just about exactly ten years ago that I decided the time had come to invent a computerized insulin pump and so set out to do it and Jack is the result.

[Applause.]

Mrs. **Morella**. Mr. Chairman, I am particularly pleased because Jack is my constituent.

[Laughter.]

Mr. **Nelson**. We arranged this just for you, Mrs. Morella.

Let me turn to the members for any questions or comment. I have to hasten to add that we have to move on, so time is of the essence. Any members, questions or comments?

Mr. Schiff.

Mr. **Schiff**. Mr. Chairman, I appreciate your not so subtle motion to us that we to move quickly. I have obviously a couple of generic things I want to raise. Mr. Fischell, you just happen to be sitting there first, you know, and I'd like to raise them and won't raise them again.

I want to point out so it's not misunderstood, I'm a proponent of the space effort. I believe that humankind should be exploring in space. And I understand the message of today's proceeding, which is space research leads to developments which are beneficial to people here on earth, in addition to the benefits inherent to research. But there's two gaps here that I think my constituents want to know who are paying the bill in part for this:

The first is, these spin-offs from the space effort, suppose we had put the same money into directly intended research on these subjects. In other words, suppose for the sake of argument we had taken the NASA budget and said, "We want to apply it to medical research and other such similar research." Then wouldn't you expect the results to be more pronounced in these very same areas than as a spin-off of the space effort?

Mr. **Fischell**. Of course I think that the answer to your question has to be obviously yes. If we could have NASA's budget—which they may complain is too little, just to make better devices of high technology that would derive from the space program, of course, we would be dramatically further ahead. But in the nature of the way this country is set up, it doesn't seem to happen that way.

For example, the National Institutes of Health, to whom we went for money for developing something like this, says That's not our department, our department is research, not the development of practical hardware to help subjects. So NASA was—without their program to do it, we just could not have succeeded. Of course, we think it would be great if all their budget went for such things, but that's not the way it is.

And so it's just a very—a good method to better utilize those funds that are spent is to have these spin- offs.

Mr. SCHIFF. That brings me to my second and final point:

When you talk about an agency told you, "We're here for research, we're not set up to do anything with it." That raises the question of are the American taxpayers being asked to pay for basic research while other countries then develop it into commercialization.

For example, if I may inquire, the device you've just shown us, Dr. Piotrow, that's been of direct benefit to you, I'm pleased to say, where was it manufactured?

Mr. FISCHELL. The device is all manufactured in the United States, even all the chips are made—

Mr. SCHIFF. All the chips are made in the United States also?

Mr. FISCHELL.—made in the United States. And our licensee from Johns Hopkins is an American company. And we try to do that.

As I said in my direct testimony, it would be good if we found some way that when the FDA approved things for human use that there would be a way to fund their reimbursement so that this American technology can prosper. That is a serious problem which has to be addressed an is a principal one in getting this technology to more Americans and to have it as a significant export product.

But I think you'll find that in the area of implantable devices the U.S. is a great leader: in pacemakers and things like that, most of them in the world do come from here and a lot of them are from our technology.

Mr. SCHIFF. I just want to conclude with I'm glad to hear that. It's my understanding since joining the Committee that's a minority of particular items.

And all I'm coming down to is not opposition to space research, but the belief that I hear from the constituents that the basic research to benefit all mankind is paid for more greatly by the citizens of this country and then the economics appear to go to citizens of other countries.

Thank you very much, Mr. Fischell.

Thank you, Mr. Chairman.

Mr. NELSON. Mr. Schiff, an amplified answer to your first question is that it is the force of miniaturization in America's space program that has brought about a lot of this technology. The drive to reduce volume and reduce weight that took us to the moon and that likewise in our satellite communications industry has forced the reduction of volume and weight that has brought us to the point of this miniaturization that we are seeing applied to our everyday lives.

Mr. SCHIFF. In other words, Mr. Chairman, you're saying you don't believe it would have happened absent the pressure to come up with usable parts for the space research project?

Mr. NELSON. It may have happened but it would have not happened so dramatically, so quickly, as it did, that we had to force ourselves to develop this kind of technology and so it was available to us so quickly.

Mrs. Morella.

Mrs. **Morella**. Thank you, Mr. Chairman.

I congratulate you, Mr. Fischell, for what you've done for peoplekind and especially for Dr. Piotrow. It's a great service to the country, to American University, to Maryland's 8th Congressional District.

Now, having said that and having watched your slides and having been exceedingly impressed and proud, I notice that you got $3 million from NASA and then you said that private industry has invested three-fold that amount. And your question kind of is where do we go from here if we're going to make this available.

It seems like the answer you've presented to us is for it to be paid for by insurance companies, Medicare. What is the cost—you know, if we do not get the insurance companies to become enlightened and to pick it up and see in the long run, I suppose, it could be a cost savings for doing that when you give us the figure of what it costs for diabetics, but if that doesn't come about what is the cost of the PIMS system?

Mr. **Fischell**. Well the cost of this system is approximately $8,000 for the device, which is about $2,000 more than a pacemaker, considering it has more than the electronics of a pacer and then a fluid delivery system, we think that's a fairly reasonable price when it's made in limited quantity, which it is. Some day in mass—when they make hundreds of thousands of them, hopefully the price will be less. The cost of implanting it may run another couple of thousand, $3,000—maybe $10,000 to do it.

The unfortunate thing is that though studies have clearly shown in the long term it's a dramatic saving in cost, the initial cost is higher and that's where the hang- up is to get over that initial problem.

Mrs. **Morella**. And I guess part of that marketing is what it would behoove the private sector also to do with the insurance companies and, you know, the prospective beneficiaries to do that.

How long would the instrument last? Does it need a lot of repair or—

Mr. **Fischell**. These last about—currently about five years.

Mrs. **Morella**. About five years.

Mr. **Fischell**. About five years.

Mrs. **Morella**. But as you say if you mass produce them then the cost would go down significantly and dramatically.

Well it seems—what are we doing—Do you have a concern, do you have a plan about doing something with this internationally? Would it be giving away our secrets or do we share this medical information with other countries, looking for other companies in other countries to link up with you? I mean, how do you see this internationally?

Mr. **Fischell**. Internationally I think the way that is considered is for a U.S. company to manufacture it and export it for profit. It's protected by patents in the U.S. and foreign countries, and the patents from Johns Hopkins are licensed to this company, so we're doing it to promote American technology and to help people while doing it.

Mrs. **Morella**. So you—this is your intent, to keep it in the United States.

Mr. **Fischell**. Keep control in the United States.

Mrs. **Morella**. Keep control in the United States.

Mr. **Fischell**. Yes.

What Mr. Schiff is worried about hopefully won't happen here.

Mrs. **Morella**. Yes.

Well I thank you very much. And it's good to see you, Dr. Pietrow.

Thank you, Mr. Chairman.

Mr. **Nelson**. Mr. Rohrbacher.

Mr. **Rohrbacher**. I wonder if you could amplify on the answer that you just gave about the cost to benefits in the long run. How much could technology like this save us? You mentioned that $20 billion is being spent a year on diabetes-related illnesses and this type of technology, you said there is an initial cost that's quite expensive but it would save us money in the long run. Could you amplify on that for me, please?

Mr. **Fischell**. Yes. And I'm not doing it out of my own head, so to speak, but rather referring to a recent study at the University of Minnesota on the study of economics of implantable insulin pumps.

And the big impact they have—and you know in all this we're ignoring the fact that we're going to make people healthier, happier and better—we'll take that as zero value.

But they were estimating a saving of about $2 billion a year in direct cost.

Mr. **Rohrbacher**. Two billion a year.

Mr. **Fischell**. About $2—as much as $2 billion a year in direct cost once these are into the system and being used.

Mr. **Rohrbacher**. And about—that is a requirement of what kind of investment to receive that?

Mr. **Fischell**. I don't know. I don't know what the total initial amount to be paid before one reaches that steady state.

But the indirect costs of morbidity, mortality and all this are just dramatically reduced. We don't know how much yet, but half of that cost of the $20 billion was in direct, roughly, the other half indirect. And essentially all of the indirect might be saved.

So it is—granted, there's a lot of conjecture involved. But what we see from the decrease in blood sugars, the more normal—normalization of it and the decrease in the blood lipids: cholesterol, triglycerides—which are very high in diabetics on injection—this could mean to us that we will realize all these gains for these people, both from a health point of view and from an economics point of view.

Mr. **Rohrbacher**. Well I'd like to personally congratulate you for taking the initiative to come up with this type of device and I know we all feel that way and I feel a sense of awe in front of someone like yourself. So thank you very much.

Mr. **Fischell**. Thank you. Thank you very much.

Mr. **Rohrbacher**. Thank you, Mr. Chairman.

Mr. **Nelson**. Thank you.

Now members, fasten your seat belts, because we're going to have to start moving. We're going to have to basically keep all of these panels to about ten minutes apiece throughout the first half, and five minutes apiece, which was the scheduled time for us to get anywhere close to arriving near the appointed finish hour.

Mr. Rose.

Mr. ROSE. Okay. The second panel is going to give a presentation on the Stirling engine, which we think is going to have a great future: Mr. A. Gregory Gutgsell, who is the Executive Program Manager of Government Products, Deere and Company, from Moline, Illinois and Mr. Thomas Kennedy, Jr., President, the Kennedy Engine Company in Biloxi, Mississippi.

Mr. NELSON. Okay. Would you mind moving over and let them sit over there next to each other?

Mr. ROSE. All right.

Mr. NELSON. All right. Now starting at 11:00, there are going to be two versions of the Stirling engine available for test drive in the Rayburn horseshoe.

Gentlemen.

STATEMENT OF A. GREGORY GUTGSELL, EXECUTIVE PROGRAM MANAGER, GOVERNMENT PRODUCTS OPERATIONS, DEERE & COMPANY, MOLINE, ILLINOIS, PRESENTING THE STIRLING ENGINE

Mr. GUTGSELL. Mr. Chairman and members of this Committee, I am Greg Gutgsell, I am the Executive Program Manager of Government Products Operations at Deere and Company. We have appeared before this Committee over the past three years to apprise you of Deere and Company's investigations to look at the Stirling engine as a potential manufacturer and marketer of this device.

The engine was produced by the technology of MTI under the funding of the Department of Energy contract funding and it was administered by NASA Lewis Research Center. Congratulations are due all of your for the development of the Stirling technology, using the format of the Heat Engine Technologies Program.

Funding has resulted in an engine that, with sustained government support and private sector support, should in the next ten years perhaps be produced and help to provide some substantial results for our nation's endeavor to reduce fuel consumption and also energy use in terms of efficiency and in terms of emissions.

MTI, as the result of this endeavor, as I said, has created the most efficient small engine capable of meeting current standards, that is, the near term emissions standards for requirements for engines. And the engine itself requires only heat, and it will take but modest changes to make it available for fluid use in terms of any liquids that are currently fuels, any gases, any solids, any solar fuels or any nuclear fuels. It might be an ideal candidate for the fusion experiments that are currently being conducted.

Deere and Company, as I mentioned, is the world's foremost producer of agricultural equipment. We're over 150 years old, our 1988 year sales were $5.3 billion, and we are a proven engine innovator. We've produced over 2 million heavy-duty diesel engines in the 58 to 310 horsepower class. We are engaged in a multi-million dollar effort currently to produce a rotary engine, which is a high power density multi-fuel engine which will be available in the latter part of this year for both military and commercial use.

For many years, we intermittently observed the Stirling engine programs conducted by DOE, NASA, MTI and others, and serious attention was given to this particular Stirling engine in 1985. Over that period of time, we invested considerable resources in our attempts to determine the potential profitable commercial applicability of this engine design.

In 1986, we joined with NASA in a Space Act agreement which more formally structured our evaluative tasks. The goal was to establish Deere as a potential marketeer and manufacturer of this device. We sought also to attract logical engine users who operated or supported large fleets of step-vans such as the U.S. Postal Service, Air Force and American Trucking Association. The objective was to establish a foundation for commercial users capable of making broad-based assessments of Stirling engine development.

Impressed by favorable engine performance and encouraged by product and manufacturing improvements identified as a result of our value engineering/value improvement studies wherein we reduced the potential cost of the engine by 40 percent, we were still cautious in our assessment of the Stirling. In our opinion, this engine is not yet ready for commercial production.

Although it's registered more than 20,000 hours in terms of lab and controlled field analysis, it has yet to face the acid test by potential users. And what we suggested was that they can assess the true engine operating economics. What we really need is a user-generated engine reliability statistical base essential for commercial feasibility decisions.

Mr. NELSON. Mr. Gutgsell, we've got a rule in this Committee that we don't let our witnesses read their statements. What we want you to do is just talk to us. Just talk to us about this invention. Share with us.

Mr. GUTGSELL. Okay.

We looked to see what we could do in terms of the engine to make it commercially replicable. We drew together our value engineering/value analysis folks, asked them to see what they could do to take an engine which was laboratory-produced and see how it would be produced in terms of a diesel engine production facility. As I said, we took 40 percent of the engine cost out of it. We used proven techniques that we had developed over the years at Deere and Company.

But what we really needed was to take this innovative design and take it, from the process of innovation, take it to the field and that takes a test period: whether it be tractors or be Stirling engines. And that evaluative process was something that required a considerable investment.

And so as we drew together all of our talents, we came to Congress last year and suggested, in conjunction with MTI, that possibly what might occur was a continuation of the program, a transfer of technology, if you will. That technology, which had already been so well proven and it was demonstrated last year by having the vehicle outside, that we might be able to, in the ensuing three years, create this base which would enable us at Deere and Company to make the necessary assessment as to whether this could be manufactured.

And of course the thing that drives manufacturing in the commercial sector is are there orders. And so, with these engine users that I mentioned, the Post Office and the Air Force and some of the trucking companies, we felt that there was a good possibility that within this period of time if we could generate the substantial hardware for between 50 and 60 such engines that in the three-year period of time that we could develop the base necessary for us to make these essential decisions.

The cost of that program is in the testimony, $25 million, $5 million of which we suggested would come from the Government, $20 million from the private sector. Thereafter, in the ensuing years up to 1992, in investment totalling $85 million would have been made and we would have substantially—pardon me, $65 million and 85 percent of which would have come from the private sector. This is what we suggested that would be the orderly process of transition from what is now a very prominent technical innovation.

You know, for many, many years the Stirling engine has lured scientists just based on its theoretical potential: 85 percent fuel efficiency is its claimed potential. And for the years over, it's been a lure. You can go over to the Smithsonian Institute and see it in its basic, very, very basic form.

What's been done under NASA technology utilization management has been to take this type of technology, take it to the point that it currently is—as you'll see it outside—in vehicles that are usable, in vehicles that possess a very high potential.

We've authored some papers based on the characterization of the engine and based on its emissions which lead us to believe that it is currently responsive to all published emissions requirements and all of those that are going to be published in the near future, something certainly of great concern.

As I mentioned before, the elements associated with the small fusion experiments that are being done could indeed fuel this because all this engine takes is heat.

[The prepared statement of Mr. Gutgsell follows.]

HEARINGS ON
NASA TECHNOLOGY UTILIZATION PROGRAMS

Committee On Science, Space and Technology;
Subcommittee On Space, Science & Applications
U. S. House of Representatives

STIRLING ENGINE PROGRAM

Presented By:
A. Gregory Gutgsell
Executive Program Manager
Deere & Company, Government Products Operations

April 13, 1989

U. S. House of Representatives

Committee on Science, Space & Technology

Subcommittee On Space, Science & Applications

13 April 1989

Mr. Chairman and members of the committee, I am A. Gregory Gutgsell, Executive Program Manager, Government Products Operations, Deere & Company, Moline, Illinois. Over the past three years, I have appeared before this committee and their staff to apprise you of Deere & Company's potential role as manufacturer and marketer of the Stirling engine technology developed by Mechanical Technology, Inc., under DOE contract funding administered by NASA Lewis Research Center.

Congratulations are due you Sir, and your Legislative associates, for furthering the development of the Stirling technology over the past decade, using the format of Heat Engine Technologies Program Title III of PL95-238; management, a function of NASA's Technology Utilization Office.

Funding has resulted in a Stirling technology that, with sustained Government and private sector support, has probability of commercial production availability within the next ten to fifteen years. The MTI Automotive Stirling Engine (ASE), the result of this endeavor, should be considered one of our Nation's technical assets. It is one of the most efficient small engines, and is capable of meeting current, and the most near term, emission standards. Since it only requires heat to make it function, modest changes make it operable on all available liquid, gaseous, solid, solar and nuclear fuels.

Deere & Company, the world's foremost producer of agricultural equipment and is a leader in commercial diesel engine production, construction equipment and consumer products with 1988 sales of approximately $5.3 billion. The company, over 150 years old, has over 38,000 employees. Although an international concern, seventy-five percent of our sales are generated in the United States, and most manufacturing facilities are centered here. Deere is a proven engine innovator, having produced over 2 million heavy duty engines in the 58 - 310 hp range. Several years ago we committed to diversify our engine production base to include rotary engines. This multi-million dollar effort is conducted by our Rotary Engine Division in Wood-Ridge, New Jersey. Prototypes of the SCORE™ Stratified Charge, high power density, multi-fuel engine will be available for both military and commercial markets this year.

For many years, we have intermittently observed Stirling engine programs conducted by DOE, NASA, MTI and others. Serious attention commenced in 1985, and in the course of subsequent events, we invested considerable resources in our attempts to determine potential profitable commercial applicability of this engine design. In 1986, we joined with NASA in a Space Act Agreement, which more formally structured our evaluation tasks, to include; engine design evaluation, manufacturability and commercial market analysis. The goal was to enable Deere & Company to be better apprised with Stirling engine facts, so that the potential market and profitability could be more accurately estimated. To expand knowledge of the available user marketplace, we amplified NASA and MTI efforts as we sought to attract logical engine users; those who operated, or supported, large fleets of step vans, such as U. S. Postal Service, U. S. Air Force and The American Trucking Association. The objective was to establish a foundation of commercial users capable of making broad based assessments of current Stirling engine development. These partners participated in either a cost sharing or cooperative funding process as a measure of their dedication to the effort.

Impressed by the favorable engine performance witnessed while a program member, encouraged by product and manufacturing improvements identified as a result of Deere & Company Value Engineering/Value Analysis activities, we were still cautious in our assessment of Stirling engine commercial potential since, in our opinion, this engine is not yet ready for commercial production. The MTI Stirling technology, although it has registered more than 20,000 hours of lab and controlled field analyses, has not yet faced the "acid test" by potential users, so that they can assess true engine operating economics. At the same time, a user generated engine reliability statistical base, essential for commercial feasibility decisions, must be accumulated. Therefore, our on-going program objectives were logically expanded to confirm and refine design and value engineered improvements, manufacturability and cost effectivity. In our opinion, customers will not place significant orders until they have had substantial hands-on experience with product prototypes.

In the Spring of 1988, we together with MTI, approached Congress proposing an expanded five year Stirling engine technology demonstration program, having a total cost of $85 million. The proposal suggested that $20 million be provided during the first three years by the U. S. Government. During this same period, private funding would contribute an additional $5 million, or 20% cost sharing. The program provided for procurement and assembly of approximately sixty manufacturable MOD II V.E. Stirling engines and their operation and assessment in selected automotive fleet usage for a period of eighteen months. It was anticipated that the three year program results could lead to a reasonable decision regarding production in fiscal year 1992. With significant user response, manufacturing might have commenced in the ensuing twelve to fourteen months following industry investment of an additional $60 million for production tooling. Total program costs of $85 million, therefore, would have received 75% funding from industry. (See Table 1, Fig. 1)

Denied this vital Congressional funding, and with internal commitment to other programs of product evolution and improvement for both diesel and rotary engines, Deere lacked the personnel and financial resources to further support an independent Stirling R&D program and was forced to withdraw from the Stirling consortium.

We have participated in the transition process by continuing to cooperate to the fullest extent possible with NASA, MTI and user partners in transferring knowledge gained from our program participation. We have also supported orderly delivery of our knowledge by cooperating with NASA in professional technical presentations at SAE and other Stirling product orientation meetings, as well as those with new perspective Stirling engine manufacturers.

Since its invention over 150 years ago, the calculated, theoretical efficiency of the Stirling engine has periodically lured pragmatic scientists into efforts to practically substantiate these long claimed theoretical advantages. The U.S. Government has invested approximately $130 million in ASE Stirling technology over the past decade. Under NASA direction, this novel means of propulsion has been refined by Mechanical Technology, Inc., a prominent technical innovator. Practical Stirling engine knowledge has advanced from that of an exhibit at the Smithsonian Institute to the verge of potential commercial production. The original DOE contract provides entitlement to the U. S. Government in terms of 2.25 times its investment by returning royalties generated as a result of Stirling engine sales. Thus, commercialization insures that the taxpayers investment will eventually be recovered.

In conclusion, Mr. Chairman, we are pleased and proud to have been associated with the Automotive Propulsion Research and Development Act of 1977... which created a forum for Automotive Stirling Engine program assessment. We enthusiastically support the role of NASA and their Technology Utilization Program for their foresight and managerial prowess. In the Stirling engine, they have selected a program that has the potential for new technology implementation, satisfying key elements of our National Strategic Goals, to find new and more efficient energy sources compatible with our environmental needs.

Table 1

Stirling Engine Technology Demonstration Program Costs

(In Millions of Dollars)

	Milestones						
	FY89 Begin Program	FY90 Field Demo Start	FY91 Field Demo Complete	Program Costs (Subtotal)	FY92 Production Decision	FY93 Commence Production	Total Costs
Private Sector	1	2	2	5	25	35	65
Government	8	7	5	20	—	—	20
Total Program Costs	9	9	7	25	25	35	85

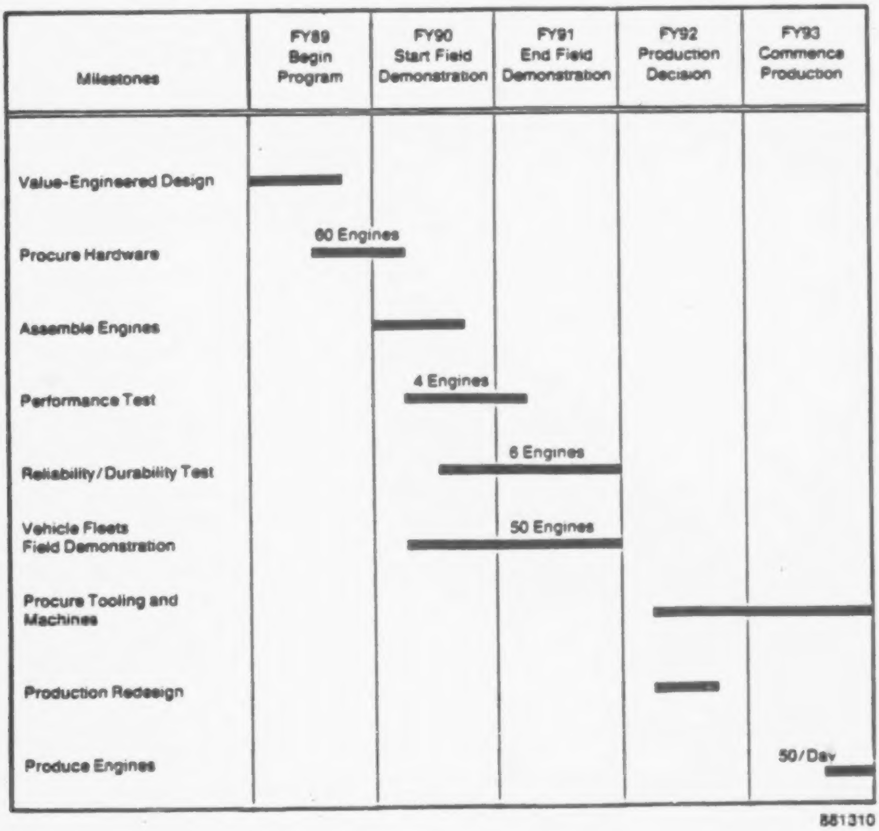


Figure 1 Stirling Engine Technology Demonstration Program Schedule

Mr. **Nelson**. All right.

Now Mr. Kennedy, you're involved in marketing this engine, is that correct?

Mr. **Kennedy**. Yes, sir.

STATEMENT OF THOMAS M. KENNEDY, JR. PRESIDENT, THE KENNEDY ENGINE COMPANY, INC., BILOXI, MISSISSIPPI, PRESENTING THE STIRLING ENGINE

Mr. **Kennedy**. My company is just a small company that would like to utilize the technology that's available from what's already been developed on the Stirling engine. We'd like to enter the market place with an engine that we can initially build and then to sell to customers like the Post Office, who can use this clean-burning engine.

It is a remarkable engine as compared to the internal combustion engine: you can touch the exhaust pipe and it won't burn you. It runs on many different fuels: methanol, gasoline, diesel fuel, things that are already available. It's really simple to work on; as far as getting service on it, if you had to pull into a dealership there would be some infrastructure changes there but it would be—the typical mechanic may be able to get some training and start working on the engine.

So that's why we would like to enter the program. We weren't involved in developing the engine, our Kennedy Engine Company. So we'd like to get involved and do some demonstration programs—build some engines and do some feasibility studies with them.

It's a remarkable engine and it's got my attention, just as being in the engine business all my life, a family-run business down there mainly involved in diesel engines, and it's quite an engine. I think everyone in here ought to go down and take a look at the Postal vehicles, that's in the front of the building here.

[The prepared statement of Mr. Kennedy follows.]

#6

Kennedy Engine Company, Inc
PHONE [illegible] FAX 601-3[illegible]
[illegible] ROAD [illegible] (CEDAR LAKE EXIT)-RT. 6
BILOXI, MISSISSIPPI 39532

COMMERCIALIZATION
OF THE
STIRLING ENGINE

A growing concern is occuring throughout the country over clean air and a deteriorating environment. The federal government, through a re-authorization of The Clean Air Act, is focusing heavily on the use of alternative fuels, and action is being taken by local governments to restrict emission levels of such pollutants as carbon monoxide and oxides of nitrogen. In states and municipalities, action is underway to comply with Federal Air Quality Standards. In Denver, Colorado, the use of Methyl-Tertiary-Butyl Ether (MTBE) is required for winter months to reduce exhaust gas emissions of carbon monoxide. A four county area in Los Angeles has approved a sweeping anti-smog plan to meet federal clean air standards which would phase in strict rules requiring use of such clean burning fuels as methanol and compressed natural gas in cars, trucks and buses. Other cities and localities are adopting similar type measures to improve the quality of the air environment. The major contributing source for most of the Carbon monoxide and Nitrogen oxides is vehicles with the majority of this air pollution coming from automobiles, small trucks, vans and public transportation vehicles primarily weighing less than 6000 pounds. Many solutions currently being pursued with existing engines will provide relief in the short term only. Use of oxygenated fuel may reduce carbon monoxide emissions by 10% , but as urban areas grow, the short term gains are stalemated with a need to find a long term solution. The STIRLING Engine, as an alternative engine, provides a long-term solution to the nation's emission problems and represents a strategic alternative for pollution abatement.

The Stirling engine is a closed cyle heat engine. This means that the working pistons are driven by a gas which is closed to outside air. The engine needs to operate at a high temperature at one end and a cold temperature at the other. Energy is provided at the hot end by heat transferred from combustion of fuel and air external to the engine pistons. Energy is extracted at the cool end by heat transferred to cooling water. The external combustion system allows the engine to burn fuel with excessively high amounts of air to insure total combustion of the fuel and the release of very low levels of emission products. In addition, the engine can operate on all available alternative fuels - gasoline, diesel, methanol, ethanol and natural gas - while maintaining low emissions. For example, as the chart depicts (see attachment I), Federal standards for carbon monoxide and nitrogen oxides are 3.4 and 1.0 grams/mile *respectively.* The Stirling Engine, whether operating on gasoline, methanol or natural gas, emits these pollutants at levels significantly below the standard and those of existing engines.

The Stirling Engine Program was conceived by Congress in 1978 under Public Law 95-238 and was sponsored by the Department of Energy and managed by NASA/Lewis Research Center. The Stirling has been developed, prototyped and tested by NASA through its prime contractor, Mechanical Technology, Inc., and it has been shown to be manufacturable with competetive costs.

Although the Stirling engine was invented in 1816 by a Scottish minister, Robert Stirling, it did not offer the power variations and transient operation characteristics of the spark ignition and diesel engines. The Stirling Engine is a heat engine which needs to operate at a high temperature to provide the power and efficiency needed in today's products. In early years this was not possible because materials were not available to withstand high temperatures. As in the case of the gas turbine which is also a heat engine, the engine could not be developed and commercialized until appropriate materials were available. Recall that the gas turbine was not developed until late in the second world war and was not commercialized until the early 1950's. So, too, the development and commercialization of Stirling engines has had to wait.

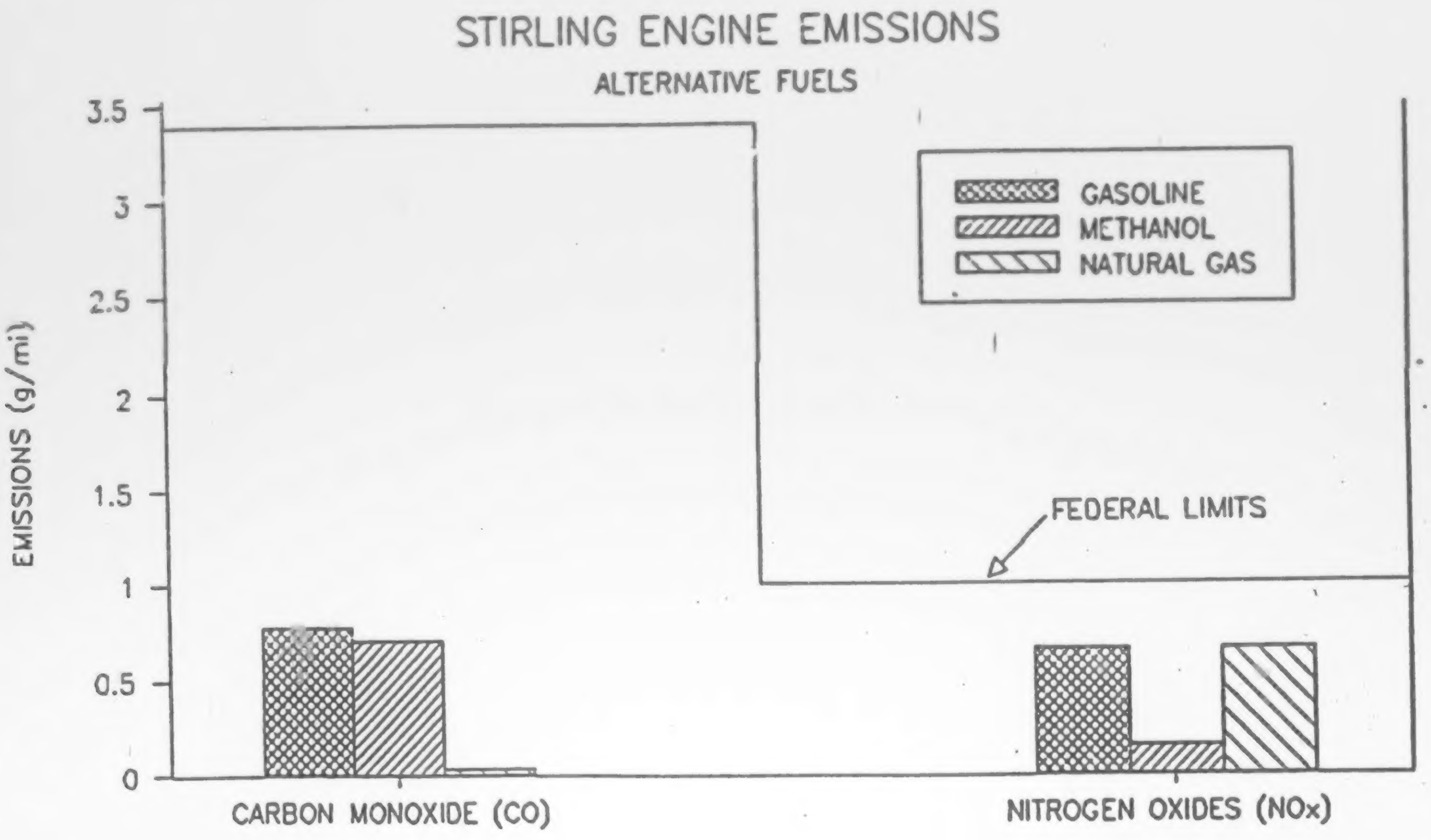
Mechanical Technology Incorporated (MTI) began to develop Stirling engines in 1975. In 1977 MTI began the development of an automotive Stirling engine for the Department of Energy and NASA. The contract was for $110 million and after more than ten years is near completion. As a result of the program and the technology developed, a MOD II Stirling engine has emerged which is ready to be commercialized.

What MTI accomplished in the development of the MOD II engine from the baseline engine through the MOD I to the present MOD II has been remarkable. Early studies of the Stirling by General Motors and Ford in the early 70's showed disappointring results and as a result dropped from their development program. MTI, through use of NASA materials technology, has brought the engine to reduced weight levels, increased acceleration of the MOD II from zero to 60 mph to 12 seconds and produced one horsepower per 5.5 pounds of weight. These characteristics are typical of conventional engines.

NASA has been working with industrial groups to speed commercialization of this technology. The Mississippi Technology Transfer Office (MTTO) at Stennis Space Center is working with NASA Technology Utilization towards commercializing the Stirling engine for prospective manufacture by The Kennedy Engine Company in Biloxi, MS. For this technology transition to be realized, MTTO is trying to focus the attention of the U.S. Congress, state and local economic development activities to support implementation of existing mechanisms and funding to bring the Stirling from prototype to pilot production.

Although the STIRLING is ready for commercializaton as an alternative engine and is considered a viable product, there is still considerable risk for a commercial company to take a flyer on initial production. The engine is potentially the "engine of the future" and The Kennedy Engine Company of Biloxi, MS hopes to be the producer of STIRLING engines; but the road from prototype to pilot production to full manufacture has many obstacles; with a major hurdle being the risk oriented funding. What is needed is an intermediate, cost shared technical demonstration and enhancement program (see Attachment II). Kennedy Engine Company is a privately held company engaged in rebuilding and remanufacturing of internal combustion engines and distribution of engine parts. Kennedy Engine Company has the largest commercial shop facilities on the Gulf Coast with engine dynamometer and training facilities well suited to accomodate fully the manufacturing aspects of the STIRLING engine.

Attachment I



Attachment II

We estimate that the cost to accomplish the next critical step, the shared technical demonstration and enhancement program to be approximately $2.5 million.

This program is intended to include:

- Manufacturing and assembling three Sterling MOD II engines. One unit will remain at Kennedy Engine Co. Biloxi, MS and two will be installed in Class I vehicles which will be demonstrated throughout the U.S.A. ($1.5 million)
- Evaluation of Sterling MOD II engines as to mechanical efficiency, fuel alternateves, cost reduction through costing of larger parts, alternative manufacturing techniques and production feasibility ($1 million)

Mr. **Nelson**. All right. Now what should we look for that will be instructive to us when we see this vehicle and its engine?

Mr. **Kennedy**. Well I guess what you'll look for is probably what you won't see is that it doesn't pollute like the engines, the internal combustion engines that are in cars today.

Now just looking at the vehicle on the outside, it won't sound any different and if you drove it it wouldn't—you wouldn't notice any difference. So from a user standpoint, it's just—you get in it, turn the key and go.

But the fact that it burns different types of fuels so we're not dependent on one type of fuel, I think that in itself is remarkable. And from the reports, the lab studies, it's more fuel-efficient than those engines that are on the road today.

Mr. **Nelson**. Mr. Packard?

Mr. **Packard**. Mr. Chairman, I would like Mr. Gutgsell, if you would, just briefly outline what new technology the engine applies.

Mr. **Gutgsell**. Yes, sir. The new technology is the capability to burn any type of fuel almost indiscriminately in any mixture. The vehicle that you see outside here will burn liquid fuels, burn alcohol, gasoline, jet fuels and also in the back it has the option of burning natural gas. It's multi-fuel capability was very attractive to us.

I didn't finish, and I don't want to leave you with the impression that Deere and Company is still involved.

Lacking the on-going commitment on the part of Congress and based on the fact that we had some very serious com- mitments and very pressing demands upon resources and personnel and in funding, we found it necessary to divert our activities back to our diesel engine and back to the rotary engine.

So Mr. Kennedy, with the Kennedy Engine Company, would represent a potential successor to Deere and Company as an engine manufacturer.

Mr. **Nelson**. Further comments or questions?

[No response.]

Mr. **Nelson**. Gentlemen, thank you very much. We're looking forward to seeing it.

Mr. Rose?

Mr. **Rose**. Our third presentation is on the Intelligent Tutoring System, which is presently being used to teach high school physics.

Mr. Robert Savely, Chief, Artificial Intelligence Section at the Lyndon B. Johnson Space Center from Houston, Texas and Mr. Bowen Loftin, the Department of Physics, University of Houston, also from Houston, Texas.

Mr. **Nelson**. Mr. Savely.

STATEMENT OF ROBERT SAVELY, HEAD, ARTIFICIAL INTELLIGENCE SECTION LYNDON B. JOHNSON SPACE CENTER, HOUSTON, TEXAS, PRESENTING THE INTELLIGENT TUTORING SYSTEM

Mr. **Savely**. Thank you.

Mr. **Nelson**. Let's just get right to the questions.

What is the space technological development that has been applied to this Intelligent Tutoring System?

Mr. SAVELY. Okay. I have a few viewgraphs to illustrate that, but it's essentially our work that we have been doing in merging training and computer science in developing intelligent computer-aided training systems to train our flight controllers.

In other words, we are merging the use of expert system technology, which is primarily the contribution of higher- order computer languages that allow us to capture in a very productive manner human expertise such as that used in training people in a few days compared to months if you use conventional computer languages.

Mr. NELSON. All right. Do you want to flash those viewgraphs us?

Mr. SAVELY. Yes, sir.

I will give you a quick overview of the NASA activity that has led to the Physics Tutor spin-off.

[Slide.]

This first slide illustrates the activity of our particular group at the Johnson Space Center. Our primary job is to bridge the gap between the research and the applications or engineering community, so we do what we call technology assessment and transfer into our line engineering environments.

In doing so, the bottom bullet pretty much sums up our work and that is the development of software and hardware environments for creating applications using emerging technologies in the computer science world.

[Slide.]

The second viewgraph indicates that our activities span the so-called artificial intelligence field, which is the field of emerging computer science concepts. So all of these activities are directed towards enhancing the productivity both in the development of applications and in their use.

An example of this is that we developed a computer program to schedule flight controllers in a few days, and this particular program reduces the work load from approximately two weeks to two hours. So in essence these computer programs that we can build today reduce activities from weeks to hours or from hours to minutes; a very productive situation.

Mr. NELSON. Why don't you tell us about the actual tutoring system and its application, what it does?

Mr. SAVELY. Okay. If I might briefly just hit the concept here...

[Slide.]

The next viewgraph indicates that training, of course, as you know is a major activity and the use of these systems allow us to provide a maintainable and consistent system across the board of any training or tutoring activity. Using the computer, we record all the student's activities, which allows us to properly utilize the expertise that's available.

[Slide.]

The next viewgraph indicates that these systems obviously can be applied throughout NASA, other government agencies, industry and education.

I think it's important here to point out that we're utilizing the basic research that DOD has been doing for the last 15 years.

[Slide.]

The training systems—

Mr. Nelson. Mr. Savely, you've got some requests from the members.

Could you turn the lights back on, please?

Mr. Savely. Okay.

[The prepared statement of Mr. Savely follows.]

The Intelligent Physics Tutor

A NASA/Johnson Space Center Technology Utilization Project

Introduction

The integration of the computer into the Kindergarten through grade 12 (K-12) instructional program began in the 1960s and has accelerated with the availability of inexpensive computing hardware and a growing amount of useful instructional software [Bork,1981]. The bulk of the computer-aided instruction (CAI) available today is limited to rather simple programs that are useful for drill-and-practice, automated "page-turning," and the administration of objective examinations. Only a small percentage of the educational software available today for grades K-12 uses simulation, extensive branching to diagnose and remediate, and/or artificial intelligence (AI) technology [Bork, 1986].

Objectives

The Artificial Intelligence Section at NASA/Johnson Space Center (JSC), in cooperation with Dr. R. Bowen Loftin, Professor of Physics at the University of Houston-Downtown, has developed expertise in the application of AI technology to the training and/or tutoring task [Loftin, Wang, Baffes, and Hua, 1988]. We have brought this expertise to bear on a specific tutoring task of interest to the nation's educational institutions: the development of an intelligent tutoring system (ITS) for use in a high school or introductory college physics course. The goal of this ITS is not the conveyance of facts and concepts but rather the transfer of problem solving skills to the student. Ultimately, this project will not only produce a useful teaching aid for students enrolled in high school or introductory college physics courses, but will also provide a development structure suitable for building additional intelligent tutors for other academic subjects which require the application of problem solving skills (*e.g.*, mathematics, chemistry, and engineering).

Technology Transfer

Since 1986, with support from NASA's Offices of Space Flight and Space Station, Robert T. Savely, Lui Wang, and Paul Baffes of the Artificial Intelligence Section at NASA/JSC have been working with Dr. R. Bowen Loftin of the University of Houston-Downtown to integrate AI technology with training/teaching methodologies to develop autonomous training or tutoring systems for NASA astronauts, flight controllers, and engineers. The development of a successful intelligent training system for Space Shuttle Flight Controllers [Loftin, Wang, Baffes, and Hua, 1988] has led to the design of a generic architecture for such systems. A number of projects are now underway at JSC, Kennedy Space Center, and Marshall Space Flight Center which apply this architecture to a variety of NASA training tasks. In addition to these activities, an intelligent tutoring system for the JSC-developed CLIPS programming language is nearing completion. CLIPS is a productive, high-order language which permits the rapid development of computer programs that model intelligent behavior. This language has been used in the projects mentioned above. The NASA/JSC Office of Technology Utilization suggested, in February, 1988, that this technology be applied to the development of an intelligent tutoring system suitable for use in the nation's educational institutions. The outcome of this technology transfer project will be a highly interactive and "intelligent" program for tutoring high school and college students in solving physics problems. This product can be mass produced and delivered economically to high schools and colleges nationwide. In addition, the methodologies employed and much of the software developed can be used to produce intelligent tutors for other problem solving domains. The effect of this technology transfer will clearly be profound and is entirely consistent with NASA's charter.

Approach

Background

The suggestion that AI technology could be applied to training and/or tutoring originated in the early 1970s [Carbonell, 1970; Hartley and Sleeman, 1973]. By the beginning of this decade a number of researchers had attempted to develop intelligent tutors for selected tutoring or training tasks. Specific intelligent tutoring systems have been built for many domains, including GUIDON (medical diagnosis) [Clancey, 1983; Clancey, Shortliffe, and Buchanan, 1984], SOPHIE (electronic troubleshooting) [Brown, Burton, and de Kleer, 1982], STEAMER (naval steam propulsion systems) [Williams, Hollan, and Stevens, 1981; Hollan, Hutchins, and Weitzman, 1984], WUSOR (reasoning) [Carr, 1977], PROUST (Pascal programming) [Johnson and Soloway, 1984 and 1985], the GEOMETRY Tutor (plane geometry) [Farrell, Anderson, and Reiser, 1984; Anderson, Boyle, and Yost, 1985], and the LISP Tutor (LISP Programming) [Anderson and Reiser, 1985] have been built and tested.

Perhaps the most successful of these, the LISP Tutor, has been shown to have a significant effect on student mastery of a skill. For example, in one controlled experiment, two groups of students attended the same lectures on LISP programming; one group completed the exercises in the traditional manner, while the other group used the LISP Tutor. The students using the LISP Tutor spent 30% less time on the exercises and scored 43% better on a post-test than those not using the LISP Tutor [Anderson, Boyle, and Reiser, 1985]. Further classroom use of the LISP Tutor at Carnegie-Mellon University for a one-semester course in LISP showed that students were able, as a whole, to achieve a full letter grade improvement in their final course grade by using the LISP Tutor when compared with previous classes that did not use the tutor [Anderson and Skwarecki, 1986]. Interestingly, poor students demonstrated the most significant performance improvement [Anderson, Boyle, and Reiser, 1985].

Approach

An ITS containing at least one semester of exercises for the first course in high school and introductory college physics is now under development (Appendix A contains the curriculum topics for this portion of the tutor). If time is available, additional exercises appropriate for the second semester will also be developed. The ITS will be designed for use by students concurrently enrolled in the standard high school or introductory college physics course and will be used to tutor them in physics problem solving. In order to provide an interactive environment suitable for detailed simulations of physical phenomena, the ITS will be delivered as a part of a workstation built around the Apple Macintosh II computer. The interface will make full use of the Macintosh II's capabilities—using high-resolution graphics, color, and sound to deliver a sophisticated real-time simulation to enhance the students' ability to relate the tutorial environment to that of the laboratory and the "real world." The CLIPS ITS strategy (adapted, in part, from the LISP Tutor) of examining user input continuously and providing immediate feedback upon detecting errors is utilized. The intelligent physics tutor is not intended to replace a human instructor or to replace the existing program of physics instruction. Instead, the tutor that we are developing will provide an interactive environment for the application of physics concepts to the solution of problems. The principal goal of the tutor will be to enable the average student to efficiently acquire problem solving skills necessary for successful mastery of high school or introductory college physics. It is anticipated that a large fraction of such physics classes could be served by the tutor, freeing the human instructor to work more closely with the slower students as well as with the more advanced students. The tutorial lessons will be integrated with the lecture/laboratory portions of the typical course, and students will have independent access to the tutor for completion of their homework.

Since the intent of the tutor is to complement an existing textbook and course in which concepts will be logically introduced, it is essential that the tutor be adaptable to a variety of texts. To this end, the tutor lessons (here "lesson" refers to a sequence of student-tutor interactions that lead to student mastery of problem solving skills pertaining to a specific concept) are keyed to physics concepts. The instructor will be provided the capability of assembling the lessons into an order consistent with the curriculum followed in the classroom and of establishing appropriate dependencies among the lessons. In addition, the instructor will have the means of choosing terms and symbols compatible with their textbook and/or preferences. Each instance of the physics tutor will contain a "global" strategy to govern the student's progression from lesson to lesson, but the tutor strategy and the semantics used in a given lesson may be altered by the instructor. The lessons for these topics will vary in length according to the complexity of problems associated with each topic. For example, the lesson for uniform acceleration in one-dimension (see below) will contain many more exercises, of varying difficulty, for the student than the lesson related to kinetic energy for rotational motion.

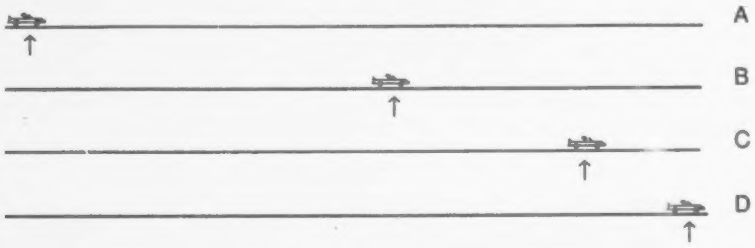
For each tutor lesson, the student progresses from the solution of a "one-step" problem, in which the available facts and the required item(s) are clearly delineated and a single relation allows the student to obtain the required result, to multi-step problems, in which intermediate results or interdependencies are required to obtain the information necessary for the final solution, to problems in which the student must, given the required item(s), obtain the necessary data through the observation of a simulation. As an example of this type of progression, consider the following four problems from a lesson on one-dimensional kinematics with constant acceleration:

1. A car starts from rest and accelerates at 2.0 m/s^2 for 10 s. What is its speed at the end of the 10 s interval?

2. A car starts from rest and accelerates at 2.0 m/s^2 for 10 s. The car then moves at a constant speed for 30 s. Finally, the car slows down at a rate of 4.0 m/s^2 until it comes to a stop. How far did the car travel?

3. A car stopped at a red light. At the moment the light turns green the car begins to accelerate at 1.5 m/s^2, and a truck, moving at a constant speed of 15 m/s, passes the car. How far will the car travel before overtaking the truck?

4.



An animated simulation or video segment shows a car starting from rest in scene A and accelerating uniformly to the location shown in scene B. The car then decelerates uniformly until reaching the position shown in scene C. Finally the car moves at constant speed to the point shown in scene D. The student is given icon "tools" that allow the measurement of time and distance (*e.g.*, a stopwatch icon can be activated by the student as the animation is in progress to obtain the time interval required for the car to move between any two positions and a measuring tape is used to measure the separation of any two points on the line. With these tools available, the student is asked to produce a position-time graph, to determine the speed of the car at various points along its path, and the accelerations that occurred between points.

In the "text-only" problems (1 and 2 above) the student, in initial tutoring sessions, may be provided with a structured environment within which to solve the problem. The listing of given information and the identification of the required item(s) can be enforced by the tutor. Further, the available relations for obtaining the required result(s) from the given information are contained in a menu and the student is allowed to select the appropriate relation(s) and interactively use them to obtain the solution to the problem. Appendix B contains an example of our current implementation of this approach using the Macintosh environment. At the top of the window is a region in which the problem is described to the student (in text or mixed text and graphics). The student has regions in the middle of the display to assemble lists of given and required data obtained from or implied by the problem. A scrollable region at the bottom of the display is used for appropriate relations, as well as an area for tutor messages to be delivered via pop-up windows. By using the contents of the lists and the posted relations, a student can use assemble his or her solution on the computer screen as if working the problem on a piece of notebook paper. At any time during the interaction, the tutor can intervene by "popping-up" a window and/or providing audible feedback. In addition, the student can obtain assistance (examples, hints, etc.) by using the help menu item.

For the most advanced exercises, the tutor in many lessons, can lead the student in abstracting real-world problems in a manner that allows the student to arrive at a solution via the methodologies conveyed in the preceding exercises. Experience has shown that most students have great difficulty in reading text describing a problem (or even viewing a photograph, detailed drawing, or video image) and producing an abstract representation of the problem that fits the problem solving patterns they have been shown by an instructor or in a textbook. Consider, for example, a video segment of a skier on a uniform slope. Most novice problem solvers have difficulty in abstracting such a scene by drawing a free-body diagram showing the skier as a point mass with the three forces (gravity, friction, and the normal force) acting on him or her. Such a step, however, is essential in order to apply Newton's Second Law and determine the skier's acceleration. The tutorial strategy in this case is to provide video stills or video segments of a physical situation and to overlay a graphical abstraction. By causing the video image to fade and the graphical abstraction to remain, students can rapidly gain experience in abstracting the essential elements of a physical description. Student mastery can be tested by allowing the student to construct the appropriate graphical abstraction from a video image and, eventually, from a written problem statement.

Error detection and remediation occur at a local level, with each student action compared to expected correct and incorrect actions. Based on the nature of each student error, appropriate feedback is given to enable the student to understand and correct his or her error. A global tutor strategy draws on a student model which identifies deficiencies of skills and knowledge demonstrated by the student in attempting to solve problems within the tutor environment. The number, type, and order of the exercises encountered by the student are determined by heuristic rules that examine the student model and the performance of the student on the exercises completed in the current lesson. The student model is also used to determine the way in which assistance is provided to the student. That is, the type, length, and tenor of messages can be tailored to the student based on the history of their experience with the tutor as contained in the student model.

As the tutor's development proceeds, a number of components will be created that can serve as the basis for the production of tutors for problem-solving domains other than physics. In particular, the use of CLIPS (or other general-purpose production languages) for error detection may be inefficient. A specialized inference engine, derived from CLIPS, will be built to optimize the local error detection of the tutor. Such a specialized inference engine can enable the tutor to, in the user's perception, instantaneously detect erroneous student inputs. The interface development will produce a set of basic objects that can also be used to build interfaces for tutors in domains other than physics. Finally, an environment for encoding the domain knowledge and the global tutoring strategy will be developed to facilitate the creation of the rule-based portions of the tutor. This environment will also be adaptable to the creation of rule-based components for other tutoring systems.

The first year of this project is dedicated to the development of a limited prototype by the personnel listed below in cooperation with a physics teacher from the local school district. The prototype is in use in a local high school and a evaluation/ development/refinement feedback loop has been established. Within two years of the initiation of the project, formal testing will begin with a small group of students with the first semester of physics exercises. Finally, during the third year of the project, refinement of the ITS and its further extension will occur.

The ITS design and evaluation will be carried out by Dr. R. B. Loftin (University of Houston-Downtown), Dr. Steve Brown (Texas Learning Technology Group), and Ms. Beverly Lee (a local high school physics teacher). Computer Sciences Corporation will provide personnel for the principal code development activity. Gary Riley and Brian Donnell of the Artificial Intelligence Section at NASA/Johnson Space Center will also contribute to the design of some tutor elements.

Personnel

NASA/JSC:	Robert T. Savely Brian Donnell Gary Riley
University:	R. Bowen Loftin, Ph.D. Professor of Physics University of Houston-Downtown
Clear Creek High School	Beverly Lee
Texas Learning Technology Group Texas Association of School Boards	Steve Brown, Ph.D. Director of Systems Research & Development
Computer Sciences Corp.:	Steve Mueller Robert Way

Robert T. Savely, the project technical manager, is Head of the Artificial Intelligence Section at NASA/JSC, and has extensive experience in managing the development of large scale expert systems. Brian Donnell developed the interface for the CLIPS ITS. Gary Riley has directed the development of the CLIPS ITS and has developed a Macintosh interface for CLIPS. Dr. R. Bowen Loftin has more than five years experience developing, with his students, expert systems for solving physics problems. This work has led him to codify the skills needed in solving certain classes of problems in physics. He initiated and has served as the principal investigator for the intelligent computer-aided training systems and CLIPS ITS projects underway at NASA/JSC. Dr. Steve Brown is the author of a PC-based tutor for the study of accelerated motion and directed the development of a comprehensive interactive video tutorial for high school physical science. Steve Mueller has been the principal code developer for the expert system portion of the CLIPS ITS project. Robert Way assisted in the development of the interface for an algebra tutor for the Apple IIGS.

Support

This project is supported by the NASA Office of Technology Utilization, the Artificial Intelligence Section at NASA/JSC, the Apple Classroom of Tomorrow Project, the University of Houston-Downtown, the Texas Association of School Boards, the National Research Council, the Clear Creek Independent School District, and the Pennzoil Products Company. Contractor support is provided by Computer Sciences Corporation.

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APPENDIX A

A List of Topics for the First Semester of a High School Physics Course
[Haber-Schaim, Dodge, and Walter, 1981]

- One-Dimensional Kinematics (Six Lessons)
    - Position and Displacement
    - Average Velocity/Constant Velocity/Instantaneous Velocity
    - Problem Solving with Position-Time Graphs
    - Uniform Acceleration
    - Problem Solving with Velocity-Time Graphs
    - Acceleration of Gravity (on Earth's Surface) and Free Fall

- Vector Analysis (Six Lessons)
    - Vector Addition in One Dimension: Displacement and Velocity
    - Vector Addition in Two Dimensions
        - Graphical Analysis
        - Trigonometry Review
        - Method of Components
        - Displacement
        - Relative Velocity

- Motion in a Plane (Two Lessons)
    - Projectile Motion (without air resistance)
    - Uniform Circular Motion

- Statics and Dynamics (Eleven Lessons)
    - Forces
    - Vector Addition of Forces in One or Two Dimensions (Net Force)
    - Newton's Laws of Motion (without friction)
        - One-Dimensional Dynamics with One Object
        - One-Dimensional Dynamics with Two or More Objects
        - Two-Object Problems in Two Dimensions
        - Inclined Plane Problems with One or Two Objects
    - Friction
        - Normal Force
        - Newton's Laws of Motion (with friction)
    - Statics
        - One-Dimensional Equilibrium
        - Review of Simultaneous Equations
        - Two-Dimensional Equilibrium

- Gravitation (Four Lessons)
    - Newton's Law of Universal Gravitation
    - Acceleration of Gravity
    - Satellite Orbits
    - Kepler's Third Law

- Energy (Five Lessons)
    - Work

    - Kinetic Energy
    - Work and Kinetic Energy
    - Gravitational Potential Energy
    - Conservation of Mechanical Energy

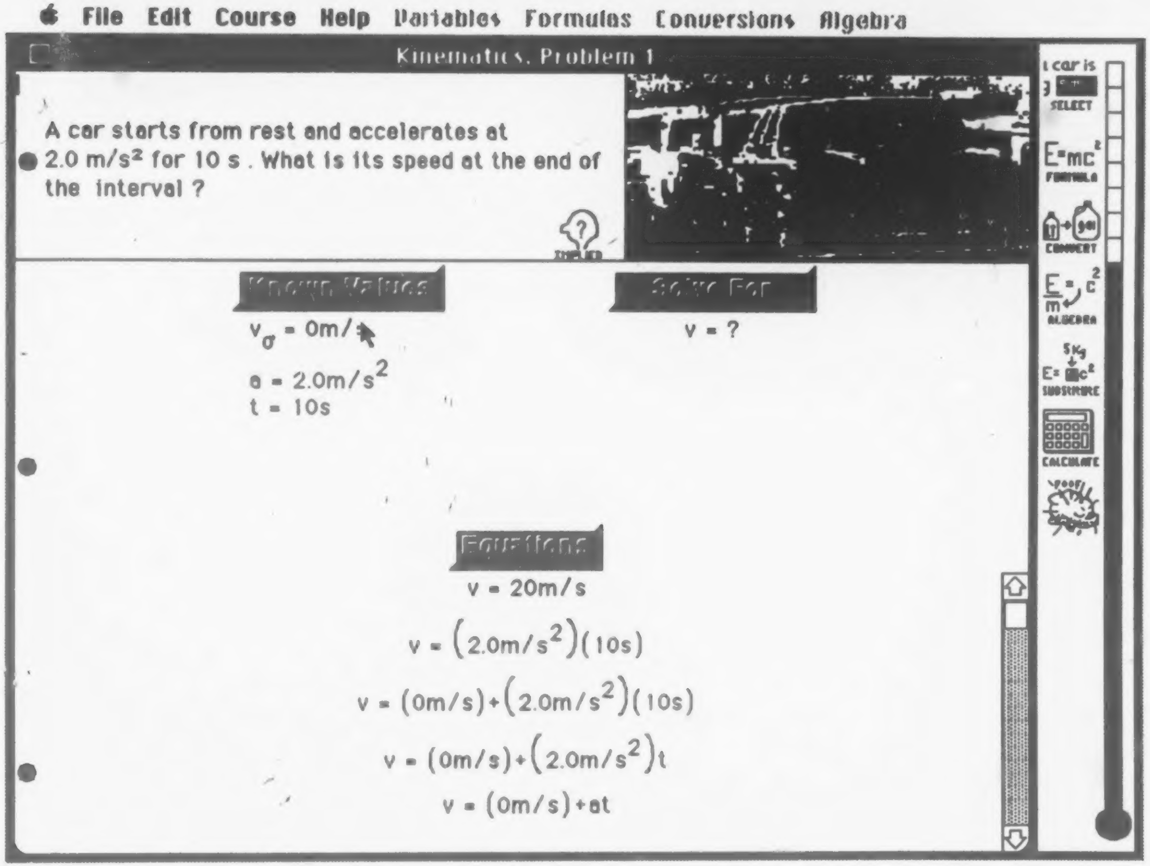
- Linear Momentum (Six Lessons)
    - Momentum and Impulse
    - Newton's Second Law (Momentum Approach)
    - Conservation of Momentum
        - Recoil
        - Collisions
            - Inelastic
            - Elastic
    - Center of Mass

- Rotational Kinematics and Dynamics (Seven Lessons)
    - Kinematics
        - Position and Displacement
        - Average Velocity/Constant Velocity/Instantaneous Velocity
        - Uniform Acceleration
    - Dynamics
        - Moment of Inertia
        - Newton's Second Law
        - Angular Momentum
        - Kinetic Energy

- Oscillations (Seven Lessons)
    - Restoring Forces
    - Mass-Spring System
        - Hooke's Law
        - Newton's Second Law
        - Elastic Potential Energy
        - Conservation of Energy
        - Period and Frequency
    - Simple Pendulum

- Thermodynamics (Eight Lessons)
    - Kinetic Theory of Gases
        - Gas Law
        - Kinetic Energy and Temperature
    - Calorimetry
        - Constant Phase
        - Phase Changes
    - Thermal Energy Transfer
        - Conduction
        - Radiation
    - First Law of Thermodynamics
        - Work
        - Internal Energy and Cyclic Processes

APPENDIX B
Example of Current Tutor Interface



File Edit Course Help Variables Formulas Conversions Algebra
Kinematics, Problem 1
SELECT
FORMULA
CONVERT
ALGEBRA
SUBSTITUTE
CALCULATE
POOF!
Known Values
Solve For
Equations

A car starts from rest and accelerates at 2.0 m/s² for 10 s . What is its speed at the end of the interval ?

Known Values

v_o = 0m/s

a = 2.0m/s^2

t = 10s

Solve For

v = ?

Equations

v = 20m/s

v = (2.0m/s^2)(10s)

v = (0m/s)+(2.0m/s^2)(10s)

v = (0m/s)+(2.0m/s^2)t

v = (0m/s)+at

Mr. **Nelson**. Just talk to us and give us some of the examples. Maybe you've got some of the hardware here that you want to point to.

Mr. **Savely**. Okay. I'm going to ask Professor Loftin to discuss the Physics Tutor in general, but some of the systems that we've developed so far include systems to teach our flight controllers to deploy satellites, to teach engineers how to use computer languages and, for the—I guess for the sake of time here we'll skip over—well we have another system that we're building to teach our mission specialists to use the instrument pointing system and the vacuum system on board Spacelab.

And I'll ask Bowen Loftin to now discuss the Physics Tutor in more detail and the hardware that we have available for demonstration.

Mr. **Nelson**. Mr. Loftin.

STATEMENT OF DR. BOWEN LOFTIN OF THE DEPARTMENT OF PHYSICS, UNIVERSITY OF HOUSTON, TEXAS, PRESENTING THE INTELLIGENT TUTORING SYSTEM

Mr. **Loftin**. Mr. Chairman.

You ask any teacher of physics in the high school or beginning college environment and you'll find that their biggest problem is time: one teacher, 30 students—

Mr. **Nagle**. We're familiar with that.

Mr. **Loftin**.—in a classroom in high school; I have hundreds in my classes.

If I could spend time with every individual student in my class every day, I could have a pile of A's and B's in my classes instead of 60 percent of the people dropping out of my class. So it's really a matter of people and time that hurts us in conveying our current technology to our students really.

The tutor system we've built here is designed to work with a teacher, with their textbook, with their curriculum, but to be there with the student. Two tables down here is a MacIntosh II, and I invite you to come by a little later on and look at it in operation. What we're focusing on here is conveying problem-solving skills to the individual student.

Imagine, if you will, 35 of me available at one time to a classroom of students, standing behind them, watching them solve problems, knowing exactly what's going through their minds, knowing exactly where their difficulties lie and correcting, hinting, nudging them along as appropriate to do the right thing.

Can you imagine how much more rapidly we could get people to learn to solve problems efficiently, skillfully, if we had that kind of technology available?

You see, we've got a problem in this country: we started off in the Sixties with computers available for the first time, Apple being the predominant manufacturer of those kinds of computers, but they were limited in ability.

The kind of CAI, computer-aided instruction, programs available at that time, and today even, were very limited: drill and practice, simple kinds of things. But now we have the technology that Bob Savely and his bunch have developed, we have the computers like the MacIntosh II there to deliver it on, we can really make a difference today in what can happen in a classroom. And at home, for that matter.

Let me just show you a couple of slides here which give you an idea of the interface you'd see on this particular system, and you can see it in operation yourself a little later on.

[Slide.]

The interface basically provides people with a problem statement; a video or graphics segment can be implanted within the system itself and, by using a mouse device and a menu bar available at the top of the screen there, one can go through the actions of solving the problem on the computer screen exactly like you would do it on a piece of paper if you were sitting at your desk at home.

The difference is the computer is watching what you are doing, as I would watch what you're doing in my office, for example, and every time a correct step is made, positive feedback can be given and say, "Hey, you're on the right track, you're doing good"; if mistakes are being made, we can give you the appropriate kinds of hints to push you in the right direction.

[Slide.]

One can take the text that's available there in the problem statement and, by working with it, directly implant at the bottom of the screen there the various givens and the various required elements of the problem before you and then select appropriate equations to work with in solving the problem.

[Slide.]

If you need help, we can help you find out how to do a particular operation through a simple menu device; we can provide feedback both audibly as you can hear today in the demonstration and also through video.

[Slide.]

For example, here's me, telling you that you're doing something wrong which you shouldn't be doing. I tried to look mean in this particular picture, which is hard for me to do, but it gives you an idea—we can implant good quality video, which doesn't come through that well in this particular viewgraph here, and very good quality sound to talk to, work with the student, almost as if I were there with them.

[Slide.]

And when you're done, you get a little pat on the back from me.

[Laughter.]

Mr. **Nelson**. So what you have is a much more complicated system here that isn't the typical yes/no computer program but it gives elaborate questions and answers.

Mr. **Loftin**. Exactly, Mr. Chairman.

Mr. **Nelson**. Now how did that come from the space technology?

Mr. **Loftin**. I began working with Bob Savely here in '86 to help flight controller training at NASA/JSC. As you may well appreciate, training is directed primarily at crew. That's a big job. You've been through some of that, you know what it's all about.

The flight controllers, system engineers, train on their own. Basically, OJT, on-the-job training is the primary means of delivering training to those people. It is great, but it's inefficient as hell.

We're talking about four years to get a person from the doorway to the point where they can actually be effective on a console, either at Kennedy or at Johnson Space Center, primarily because there are so few people who know the job and so many who need to know the job, just like our problem in the educational sector.

So our job here was to try to clone, that is, develop systems that could multiply the expertise of the trainers we have, who are great people but few in number, and be able to deliver that training technology simultaneously to as many people as we might have.

And we've been successful in building a system for the flight controllers at JSC to learn to handle deploys of satellites, we're working with Marshall Space Flight Center and Kennedy Space Center to develop training systems for them as well.

This technology had a direct transport over into the educational world, where I am of course based, and it seemed obvious to me when our TU people came to us and said, "Hey, how about moving this technology over into education?" And this was an obvious fit for us. And being a physicist, a physics tutor was an obvious thing for me.

When you consider that perhaps one to three teachers of physics are certified in Texas each year and twice that number may leave the profession, you have an idea of why the problem exists and what we're trying to do to solve it.

Mr. NELSON. Mr. Savely, you might want to introduce some of this training into the astronaut office. I remember some of the old computer programs there that were the simple yes/no stuff and it was really pretty boring. So this sounds a lot more lively.

Any comments, questions for the panel?

Mr. Rohrbacher.

Mr. ROHRBACHER. Just very quickly. I'm very enthused about what we've heard today in terms of what you're developing. American education, we all will agree, is so important to the future of the country, and it's so often that we see that our high schools and grade schools are teaching kids how to use technology in some cases, but they're not using technology in how to teach the kids. And I just would like to commend you and to thank you for the work you're doing, because I think that it offers great opportunity and I hope that our education system takes advantage of the potential that technology is opening for us.

Mr. SAVELY. Thank you very much.

Mr. LOFTIN. Mr. Chairman, one comment if I may:

We're very proud that the Texas School Board Association, which has basically the entire State of Texas at its disposal, and Apple Computer, through their Classroom of Tomorrow Project, are strong supporters of our particular work here and can help actually translate that into a product throughout the entire country.

Mr. SENSENBRENNER. Mr. Loftin, do you have any assessment as to what difference there is in motivating kids in utilizing your program versus utilizing the more traditional program?

Mr. LOFTIN. There is good data from Carnegie-Mellon University, where my colleague, John Anderson, has worked with thousands of students with similar kinds of tutoring devices. These devices can produce at least one letter grade improvement in performance over the course of a semester for the average student and two letter grades for the poor student, as an example of what can be done, what's been demonstrated so far.

Mr. SENSENBRENNER. Maybe you ought to have the School Board Association send out some kind of a thing to all of the members saying this is how you have your students in your district get an A in physics and you might get it a little bit more popularly adopted.

Mr. LOFTIN. That's our intention.

Mr. NELSON. Mr. Rose, next panel.

Thank you.

Mr. Andrews has—

Mr. ANDREWS. Mr. Chairman, if I could, just very quickly, I'll be very brief. Thank you, Mr. Chairman, for giving me a few seconds.

I'm delighted you all are here from Houston and this really is a perfect example of how indirectly and tangentially industries can spawn off some of the research that's on-going at NASA, especially the Manned Systems Technologies at the Johnson Space Center.

I'm curious if you could tell us, what in general will this kind of system cost? What kind of cost numbers would this be?

Mr. LOFTIN. Mr. Chairman, it's really difficult to predict exactly what's going on here in terms of cost, but given the fact that the technology being paid for by private donations primarily from Apple Computer, from Pennzoil, one of our supporters from Houston, and also by the TU Office, the investment is small: $600,000 for this project over three years.

I think if you market it for less than $100 per program, maybe much less than that, and the technology we have down on the table right here, oh, probably $4- to $5,000 right now, but in two or three years we're talking about half that or less. So I think it's feasible to see this spread, not only through classrooms but also in home use as well over time.

Mr. ANDREWS. Now also, is it not correct that right now this is available, this kind of system can be made—

Mr. LOFTIN. It's not available. This is still in development, we've not finished this project.

Mr. ANDREWS. What's the time frame?

Mr. LOFTIN. We will be through in about 2-1/2 years. We're six months into a three-year program right now. And we're the first program that I know of that is actually moving directly towards commercialization as opposed to pure research.

Mr. ANDREWS. Right. We're delighted to have you here. Thank you.

Thank you, Mr. Chairman.

Mr. NELSON. Thank you, Mr. Andrews, we appreciate it.

Mr. ROSE. Panel number four is to present the information on the Sewage Treatment Center now being used in the Town of Monterey, Virginia: Mayor George McWhorter, Jr., from Monterey, Virginia is with us as well as Dr. Wolverton, one of our Senior Research Scientists at the John S. Stennis Space Center in Mississippi.

Mr. NELSON. And we are going to hear about the application of space technology to sewage treatment by virtue of what was developed for space flight and extended space flight, is that correct?

Mr ROSE. That's correct.

STATEMENT OF DR. BILLY C. WOLVERTON, SENIOR RESEARCH SCIENTIST, JOHN C. STENNIS SPACE CENTER, BAY ST. LOUIS, MISSISSIPPI, PRESENTING A SEWAGE TREATMENT CENTER

Dr. **Wolverton**. Thank you, Mr. Chairman, Subcommittee.

What we're looking at here is technology that we've been looking at to develop for a closed system using natural biological processes for one day supporting life, recycling waste and air in a space station or moon base.

Now this technology, the TU program has been supporting the development of this to solve problems here on earth: simple problems like septic tanks, small communities and as we all know the grant programs are going away for small towns to solve their wastewater treatment problem.

So what we have done here over the past 15 years, NASA has done at Stennis, is look at using aquatic plants, nature, to where we use our wastes, whether it be domestic waste or toxic chemical waste as a hydroponic solution to grow plants and little creatures that grow in the root zone of plants and by very carefully manipulating it as the waste flows through it—and we have slides where we want to show you that once we get them set up—that purifies the waste.

Now this, in my opinion, is not only cost effective, as we will show you from a number of towns that used it, but it is a process, if we continue to multiply and grow here on earth, we're going to have to convert not only our industrial waste but our domestic sewage through plant growth processes to stabilize the ecological imbalance of gases we hear so much about, the greenhouse effect.

So what I would like to do is go through a slide presentation showing you, from the simplest single home units to small towns, where this technology is now being used very cost-effectively.

Now we are also starting the beginning of biomass farming, but the reason for using this technology is simply because it's cheaper and easy to operate.

Mr. **Nelson**. Mr. Mayor, we're glad to have you here today.

Mr. **McWhorter**. Thank you.

Mr. **Nelson**. You are the mayor of the town in Virginia in which this plant is under operation, is that correct?

Mr. **McWhorter**. That's correct. We are one of—well I guess we are the only one in this section of the country. There are a number of plants down on the Gulf Coast where they have a quite a bit different climate than we do that are using it. But NASA's primary interest in our using it was to see how it would act in a colder climate.

Mr. **Nelson**. Which part of the state is Monterey, Virginia in?

Mr. **McWhorter**. If you remember, the northern border of Virginia runs generally northeast-southwest, and about the middle of the state is a peak sticking up into West Virginia; that's us.

Mr. **Nelson**. I see.

Well we welcome you, Mr. Mayor. We're delighted to have you.

Mr. **McWhorter**. Thank you.

Mr. **Nelson**. You folks are the most courageous of all public servants, because you're there right on the front line of defense, day-in and day-out. We can at least leave town.

[Laughter.]

Mr. **Nelson**. And frequently do.

[Pause.]

[Slide.]

Dr. **Wolverton**. I put this up—and I'm afraid you can't see it too well—but it shows a schematic of waste going through one of these hydroponic systems where plants are growing.

In the upper one we have rocks in it where the waste slowly flows through or is purified; the lower one is where we have an aquatic grass that can be used in the warmer climates to convert the waste into protein, animal food, et cetera.

[Slide.]

This is just to give you an example of the number—and if you'll notice, Monterey is the first one, which the Mayor will discuss a little later on; the other is a list of the little towns throughout Louisiana, Mississippi, Alabama, including single homes, small towns, even industrial operations, over on the left.

[Slide.]

This is an example of the simplicity of it. The simplest application is in rural areas. We have septic tanks and have problems with leach fields where the sewage is not properly treated or you get groundwater contamination.

[Slide.]

Here is an actual application. And what is happening here—this is on a beautiful waterfront lot—is the waste from the septic tank is used as a nutrient, a food source, to grow these nice plants with while it's purified. It's very simple: gravity flow, no cost involved once you install it.

[Slide.]

This is a scale-up. This is a mobile home park that has about 27 or-8 homes on it and, again, in the center of this, this sewage treatment plant was used as a park: you see no waste, you smell no waste, kids can play in it, it's just a beautiful flower garden while the waste is being treated in a most economical way.

[Slide.]

This is showing the nice clean water coming out in a ditch below it.

[Slide.]

Here is a much larger one in northern Louisiana that treats the waste from about 2500 people, a small town—

Mr. **Packard**. What's unique about the hyacinth that it can absorb this kind of waste?

Dr. **Wolverton**. Well this is not hyacinths. The earlier work we did with hyacinths—hyacinths have a certain drawback in that they will only grow in warm climates and fresh water, so over the years—we've been working on this for some 15 years—the demand for more aesthetically desirable plants, more cold-tolerant plants, we have evolved into this.

Now the hyacinth, of course, floats on the water and you have to have open water, whereas these rooted plants, and there is a whole number of them: calla lilies, canna lilies, water irises, but most aquatic plants, in their root zone, while waste is flowing through, they support a large population of microorganisms that feed off of the waste and produce fragments that the plants use a food; it's kind of a symbiotic relationship.

So there's a number of plants, not only the hyacinths, that have that characteristic if they are aquatic or semi- aquatic.

[Slide.]

The one you just saw and this one is a canna lily. It's a semi-aquatic plant. It's a flowering plant that will grow both in the water and out of the water. Now this is the largest system to date, installed using this technology. This is a system here to treat 3 million gallons per day, a small town of about 25- or 30,000; Denham Springs in Louisiana. And it is a flower garden being cultivated while the waste slowly flows underneath three five-acre filter systems, as you see here.

Mr. NELSON. Dr. Wolverton, let me interrupt you here now.

Would you all turn back on the lights, please?

Now take for us—and the members might want to refer to this particular booklet that you have. All right, what you're doing is you're taking this sewage water, you're running it through a series of plants that continue to purify and the whole purpose is to develop a system that can be used on the space station.

Dr. WOLVERTON. Absolutely.

Mr. NELSON. All right. Now tell us about that.

Dr. WOLVERTON. Okay. If we're to stay for long times in outer space we're going to have to come up with some kind of bioregenerative system, we can't just continue to package it and bring it back.

Also, when we seal ourselves away from the earth's normal environment, plants, which produces oxygen and takes the CO2 out, we run into problems with trace contamination, indoor air pollution, as long as the waste. So the ultimate goal for the space program is to take all of our waste, recycle it through a plant system that can not only purify the waste but grow plants indirectly for supplying food, revitalizing and purifying the air all in one. That's the ultimate goal, of course, for the space program.

Mr. NELSON. And that's called the closed loop system.

Dr. WOLVERTON. The closed loop system.

Mr. NELSON. And you would presumably have that system on a spacecraft going to Mars.

Dr. WOLVERTON. Yes, sir.

Mr. NELSON. And it is this early NASA research for space that you are now applying to these cities?

Dr. WOLVERTON. That's right.

Mr. NELSON. Members?

Mr. Olin, welcome to the Committee.

Mr. OLIN. Thank you, Mr. Chairman. I apologize for being late. I want to say hello to my constituent, Mr. McWhorter.

I would only say that I've watched this evolve in Monterey, in Highland County. It's a very small county of 2500 people. And in his little town he was mandated by the EPA to put in a very expensive secondary treatment scheme and, being an engineer and being sort of obstreperous, he basically refused to do that. He said there are other ways of doing it that are better.

And so I've watched the evolution of this and been there when he planted the bullrushes and see them go through the winter...

And it's—if we can keep the EPA away from us for a couple of more years so this thing can really prove itself, it's proving itself.

And I think it's a wonderful thing and this all came from the space program. It's a good example of a transition from space to ordinary down-to-earth life on the farm, as it were. I would expect this could apply to many, many small localities.

And I thank you very much and I appreciate you having Mr. McWhorter here and Dr. Wolverton to testify. This thing has quite substantial significance.

Mr. NELSON. Well we appreciate you being here and giving us that testimony.

You know, our Committee is getting an awful lot more work today. What we've already found out that we have to do is we've got to run interference with the insurance companies so that they can market the PIMS, and now we've got to take on the EPA so we can get this new sewage system out there and working. We're going to become a supercommittee before too long.

Mr. MCWHORTER. Mr. Chairman, I'm glad you made the remark about the EPA because I was going to ask your help in doing the same thing.

Mr. NELSON. Well now you have it on record, he's signed up.

Mr. PACKARD. Mr. Chairman?

Mr. NELSON. Thank you all.

Yes, Mr. Packard?

Mr. PACKARD. Just a quick question:

San Diego has been doing some work on hyacinths, as you may know, which is in my area, for some years. But I still am not sure, are we going to be growing plants and vegetables and flowers in space or—is that how it has it's space application?

Dr. WOLVERTON. There's many different applications. My personal thoughts are that we will take the wastes with aquatic plants—not necessarily hyacinths—purify the waste, take the plants that have assimilated the nutrients, use those in a compost as a substrate for growing vegetable plants on, which of course will not grow readily in raw sewage.

So I think it will probably be a two step—because we're looking not only at purifying the water and the air but completely recycling all of it in a biological process eventually.

[The prepared statement of Dr. Wolverton follows.]

Statement of
B. C. Wolverton, Ph.D.
Senior Research Scientist
Science and Technology Laboratory

John C. Stennis Space Center
National Aeronautics and Space Administration

before the

Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

I welcome this opportunity to review with you a portion of the Technology Utilization Programs at the Stennis Space Center. I would like to highlight the work being done in the area of pollution abatement.

During the past 15 years, environmental research scientists at NASA's John C. Stennis Space Center in Mississippi have been evaluating the use of biological processes which occur in nature as a cost-effective means of solving environmental pollution problems on Earth and ultimately in closed space habitats. Although the long range goal of NASA's research in this field is to solve pollution problems inherent to long-term space travel and colonization, this technology has immediate applications in our Earth's environment.

These natural processes include green plants and the microorganisms associated with the plants' natural environments. The pollutants in sewage and industrial wastewater are used as a food source for growing plants and microorganisms associated with the plant roots. As the wastewater flows through the plant root filter marsh, the pollutants are converted into plant materials. As the water flowing through the root filter is cleaned, larger microorganisms such as protozoa and rotofiers become established which feed on bacteria, viruses and any remaining water pollutants therefore finishing the treatment processes as shown in Figure 1. Also shown is a plant root-carbon system for using this technology for removing indoor air pollutants.

Efforts toward adapting this technology for use in wastewater treatment and indoor air pollution problems have been supported by the NASA Technology Utilization Office (TU). The success of this TU program at Stennis Space Center is evidenced by the information shown in Table 1. The wastewater treatment technology has been customized for use in single homes, mobile home parks, subdivisions, small towns and industrial facilities. It has proven to be environmentally safe and cost effective. The City of San Diego, California, is evaluating this technology for use in solving water shortage problems by recycling domestic sewage for potable water.

Very promising results in solving indoor air pollution problems using this NASA technology have been achieved. A simple system employing a combination of houseplants and activated carbon for purifying and recycling indoor air is being manufactured and marketed by a small company in Texas. A diagram of this system is shown in Figure 1.

Other commercial spinoff applications being pursued are in the areas of landfill leachate treatment; hazardous waste disposal; aquaculture water treatment and reuse; waste disposal from meat, food, poultry and dairy processing plants, paper mills and runoff water from feed lots and agricultural operations. Additional areas include using domestic sewage, industrial wastewater and acid rain producing smoke stack exhaust as a nutrient source for production of valuable plant biomass. This same process would also purify the contaminated water from these sources.

It seems ironic that while developing a technology which will help man to survive for long periods of time in space, NASA may have found a simple way to cleanup the pollution problems man has created on Earth.

CONCLUSION

Mr. Chairman, I would be pleased to try to respond to any questions you may have concerning this research. The Honorable George McWhorter, Mayor of Monterey, Virginia would now like to address your committee concerning the use of this simple, cost-effective technology for solving waste treatment problems in his small town.

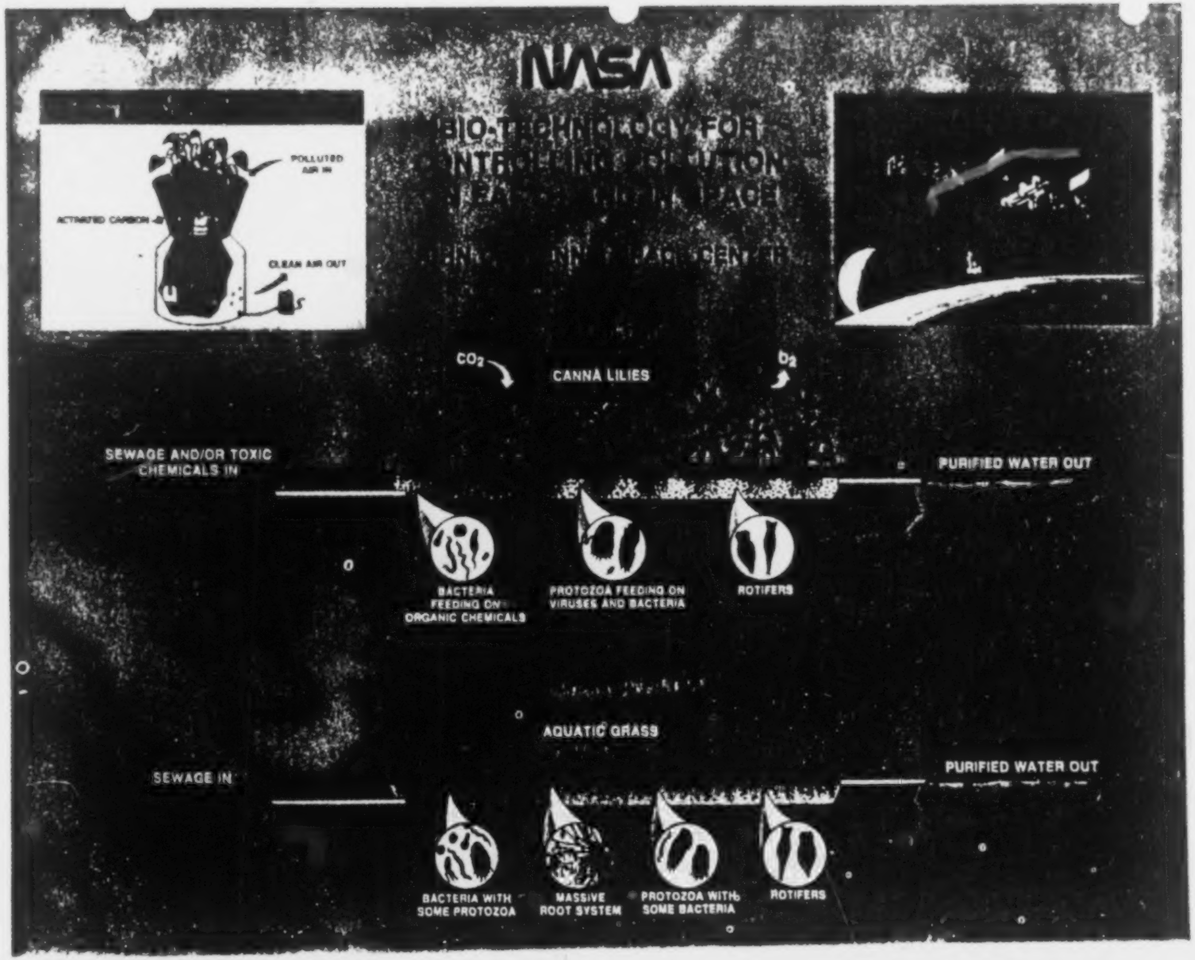

NASA
BIO-TECHNOLOGY FOR
CONTROLLING POLLUTION
POLLUTED AIR IN
ACTIVATED CARBON
CLEAN AIR OUT
CO_2
CANNA LILIES
O_2
SEWAGE AND/OR TOXIC CHEMICALS IN
BACTERIA FEEDING ON ORGANIC CHEMICALS
PROTOZOA FEEDING ON VIRUSES AND BACTERIA
ROTIFERS
PURIFIED WATER OUT
AQUATIC GRASS
SEWAGE IN
BACTERIA WITH SOME PROTOZOA
MASSIVE ROOT SYSTEM
PROTOZOA WITH SOME BACTERIA
ROTIFERS
PURIFIED WATER OUT

TABLE 1

AQUATIC PLANT WASTEWATER TREATMENT SYSTEMS USING NASA TECHNOLOGY DEVELOPED AT THE JOHN C. STENNIS SPACE CENTER, MISSISSIPPI

Small Towns, Mobile Home Parks, Subdivisions, and Single Homes		Industry	Government Facilities
1. Monterey, VA*	12. Sibley, LA	1. Natchitoches, LA* (Tenn-Gas Pipeline Company)	1. Carville, LA* (U.S.P.H.S. Gillis W. Long Hansen's Disease Center)
2. Albany, LA	13. Collins, MS*	2. Theodore, AL* (Degussa Chemical Corporation)	2. NASA, John C. Stennis Space Center, MS*
3. Benton, LA*	14. Leakesville, MS	3. Columbus, MS (Weyerhaeuser Paper Mill)	
4. Crowley, LA	15. Pearlington, MS* (mobile home park)	4. New Augusta, MS (Leaf River Forest Products—Paper Mill)	
5. Choudrant, LA	16. Pelahatchie, MS		
6. Delcambre, LA	17. Union, MS		
7. Denham Springs, LA*	18. Utica, MS		
8. Haughton, LA*	19. Summit, MS		
9. Livingston Parish, LA	20. Picayune, MS* (single homes)		
10. Mandeville, LA (City)	21. Cottonwood, AL		
11. Mandeville, LA (Green Leaves Subdivision)	22. Vredenburg, AL*		

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*In operation. All others under construction or in planning and design phase.

NOTE: A pilot system is also in operation in San Diego, CA, producing potable water from raw sewage.

WOLV2 9 001

Panel 4

NASA FY90 Auth
101-SSA
HEARING 4/13/89
NO 59

DISCUSSION OF WASTEWATER TREATMENT
AT MONTEREY VIRGINIA

By: G. E. McWHORTER, JR., MAYOR, TOWN OF MONTEREY

BEFORE THE SUBCOMMITTEE ON SPACE,
SCIENCE, AND APPLICATIONS, APRIL 13, 1989

SLIDE NO. 60 - Town of Monterey

In 1983, the town of Monterey, Virginia asked the firm of Copper & Smith, P.C. of Harrisonburg, VA to design a facility to meet the government mandate to provide secondary sewage treatment by July, 1988.

The firm recommended and designed a rotating biological contactor at an estimated construction cost of $500,000.00.

In 1984, the Town was seriously considering constructing it if government funding could be obtained. About that time, the Federal Government and the Commonwealth of Virginia announced that there would be no more grant money available for sewage treatment facilities.

For Monterey, forget the rotating biological contactor. There was no way that Monterey, with a population of 249, 190 connections to its sewer system, and half of its families existing on $14,000, many on less, per year, could finance a half million dollar sewage treatment system.

The Town, instead, instructed Rod Smith, a principal in Copper & Smith, P.C., to look for a way to comply with the mandates that the Town could afford.

Smith designed a hyacinth pond, which the Town constructed in the fall of 1985. The hyacinths met with partial success during the summer of 1986 but, as expected, they did not survive Monterey's colder than ordinary winter climate.

SLIDE NO. 61

The Town was preparing to construct a greenhouse-type structure and heating system to protect the hyacinths during the cold months when Smith read a publication by Dr. B. C. Wolverton on microbial filters using higher plants. A proposal to use this technology by retrofitting the hyacinth pond to a microbial filter was submitted to the Virginia State Water Control Board and the Virginia State Health Department in February, 1987. Subsequent meetings with Health Department personnel failed to achieve their approval.

To learn more about the process, a delegation from the Town, along with Rod Smith attended Dr. Wolverton's presentation to a Maryland Health Department Seminar in Annapolis in August 1987.

Dr. Wolverton and Mr. Ray Gilbert, both of NASA, were kind enough to spend as much time as needed with the Town delegation and Smith after the meeting.

SLIDE NO. 62

Dr. Wolverton assured us that his technology was working in several areas of the country and he felt certain it would work for Monterey. The only untested factor was the colder winter climate of Monterey,as it is in the Alleghany Mountains at an elevation of 3,000'. Mr. Gilbert volunteered the help of his department in securing Health Department approval.

The Town then asked for help from State Senator Frank Nolen, who arranged a meeting between officials of the State Health Department and State Water Control Board and Dr. Wolverton and Mr. Gilbert.

Mr. Gilbert told the group of NASA's desire that the private sector benefit from their technology and Dr. Wolverton explained in detail the microbial filter-plant technology he developed in NASA's laboratory in Mississippi. He recommended bulrushes as the plants to be used.

At the conclusion of the meeting, SHD & SWCB approved Monterey's use of the NASA technology on an experimental basis and extended the deadline to achieve secondary wastewater treatment to August 1993.

SLIDE NO. 63 - Schedule showing experiment phase and construction phase. (Exhibit A)

In late April and early May 1988, the Town converted the hyacinth pond into a microbial filter and planted 800 bulrush plants from Louisiana and 800 from Pennsylvania.

SLIDE NO. 64 - Schematic of WWTP. (Exhibit B)

SLIDE NO. 65 - Hyacinth pond upon completion in 1985.

SLIDE NO. 66 - Cross section of filter. (Exhibit C)

SLIDE NO. 68 - Availability of rock for filter media.

SLIDE NO. 69 - Placing filter media.

SLIDE NO. 72 - Splitter box details.

SLIDE NO. 73 & 74 - Planting bulrushes.

SLIDE NO. 75 - First 800 bulrush plants.

SLIDE NO. 77, 78, & 79 - Growth of plants May to August 1988.

SLIDE NO. 80 - September plant growth.

SLIDE NO. 81 - LA bulrush growth to November.

SLIDE NO. 82 - Local bulrush growth to November.

SLIDE NO. 86 & 87 - December 15th snow, 4°F. three days after 12°F below zero low temperature for year.

SLIDE NO. 89 & 90 - December 31, 1988 warm weather between Christmas and New Year.

SLIDE NO. 94 - One of several snows, January & February.

SLIDE NO. 95 & 96 - Dead of Winter, February 24, 1989, 4°F; still plenty of green.

SLIDE NO. 99 - BOD_5 Chart. (Exhibit D)

SLIDE NO 100 - TSS Chart. (Exhibit E)

SLIDE NO. 103 - Schematic of future expansion. (Exhibit F)

All data gathered to date show that the microbial filter-plant technology developed by NASA will satisfactorily provide secondary sewage treatment in the higher altitude and colder climate of Monterey. We plan, therefore, to expand the existing experimental phase into a larger, permanent facility.

The design, construction, and operation of this system is something the Town can achieve with in-house personnel, local construction crews, equipment, and material. This will eliminate the purchase and installation of expensive machinery and equipment, high energy operating costs, and expensive maintenance. It is probable that the use of technology developed by NASA, rather than conventional methods, can reduce the Town's costs of meeting sewage treatment mandates as much as 75 percent.

For this, the Town is extremely grateful to Dr. B. C. Wolverton and Mr. Ray Gilbert for their invaluable assistance with the bulrush project and to NASA for developing a means to avoid bankrupting the Town for future generations.

NASA's technology could well provide a wave of the future for large and small municipalities to have an economical means for a cleaner environment.

Respectfully submitted,

G E McWhorter Jr
G. E. McWHORTER, JR., P.E.
Mayor, Town of Monterey, VA

FIGURE 6

MONTEREY, VIRGINIA • PILOT PLANT STUDY- PHASE II
TIMETABLE OF DEVELOPMENT

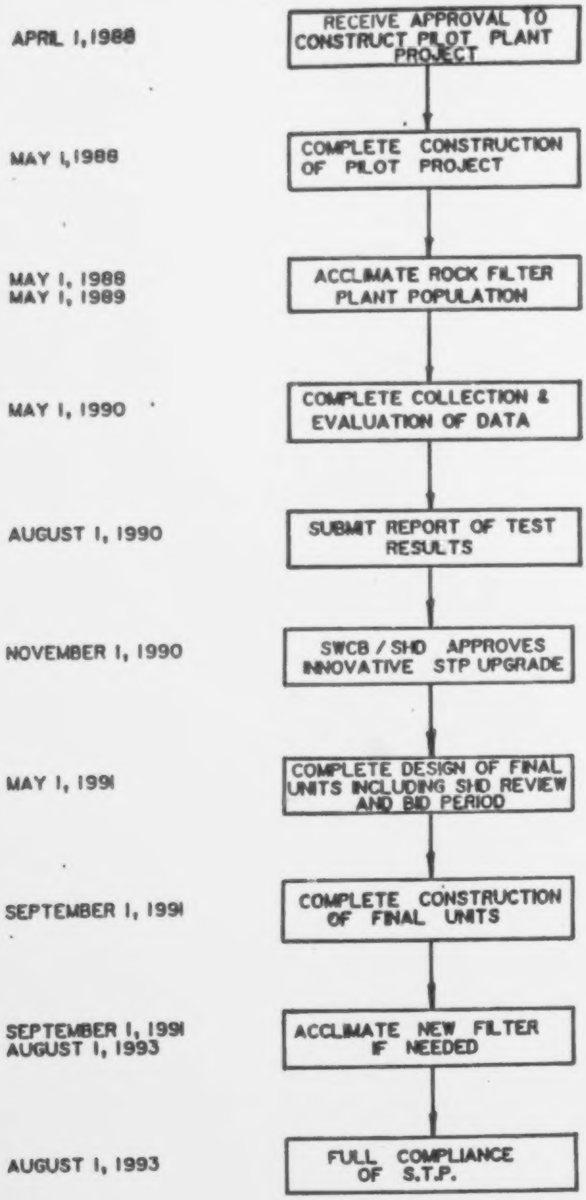

APRIL 1,1988
RECEIVE APPROVAL TO CONSTRUCT PILOT PLANT PROJECT
MAY 1,1988
COMPLETE CONSTRUCTION OF PILOT PROJECT
MAY 1, 1988
MAY 1, 1989
ACCLIMATE ROCK FILTER PLANT POPULATION
MAY 1, 1990
COMPLETE COLLECTION & EVALUATION OF DATA
AUGUST 1, 1990
SUBMIT REPORT OF TEST RESULTS
NOVEMBER 1, 1990
SWCB / SHD APPROVES INNOVATIVE STP UPGRADE
MAY 1, 1991
COMPLETE DESIGN OF FINAL UNITS INCLUDING SHD REVIEW AND BID PERIOD
SEPTEMBER 1, 1991
COMPLETE CONSTRUCTION OF FINAL UNITS
SEPTEMBER 1, 1991
AUGUST 1, 1993
ACCLIMATE NEW FILTER IF NEEDED
AUGUST 1, 1993
FULL COMPLIANCE OF S.T.P.

EXHIBIT A

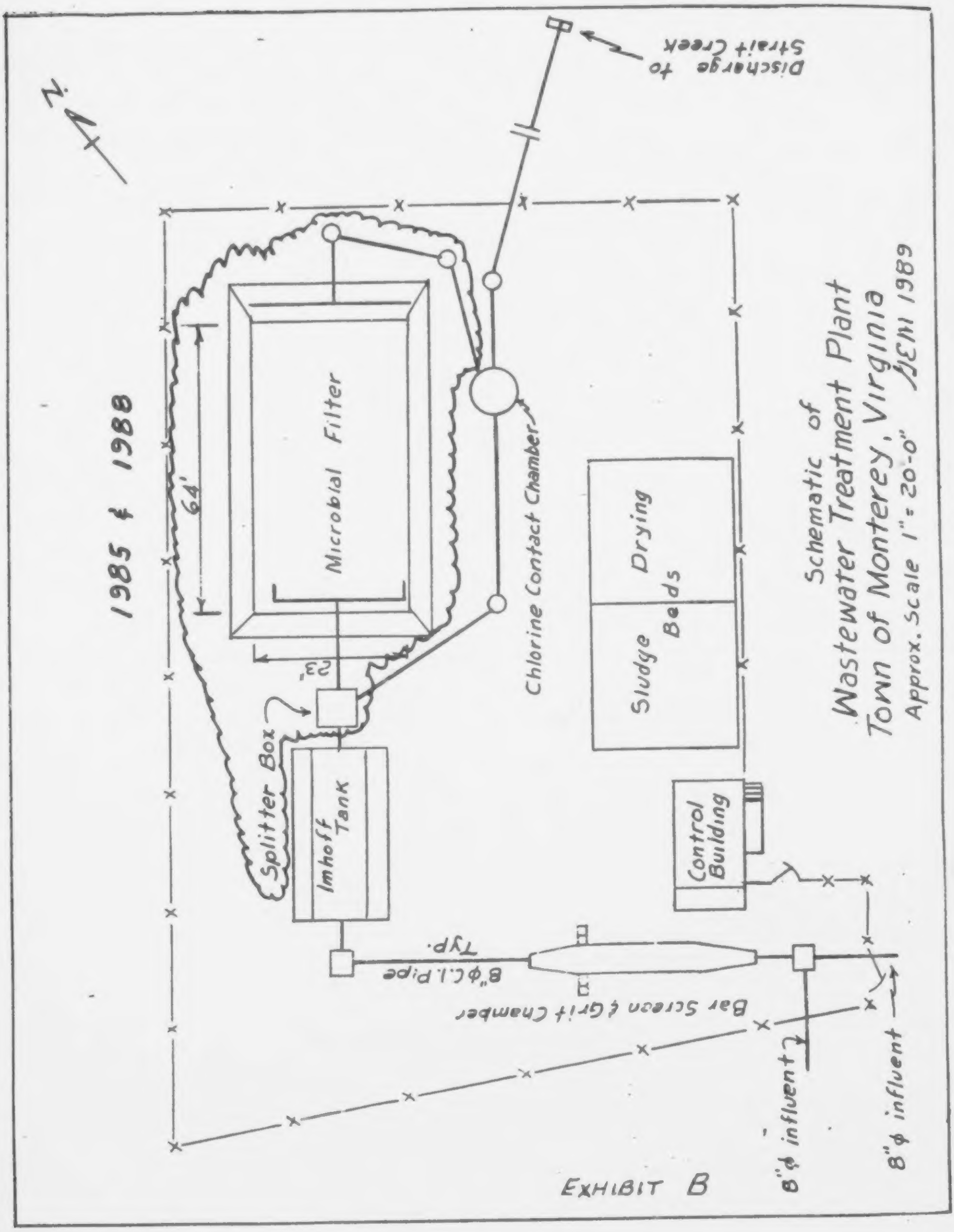

1985 & 1988
N
Discharge to Strait Creek
64'
23'
Microbial Filter
Chlorine Contact Chamber
Splitter Box
Imhoff Tank
Sludge Drying Beds
Control Building
8"φ C.I. Pipe Typ.
Bar Screen & Grit Chamber
8"φ influent
8"φ influent
Schematic of
Wastewater Treatment Plant
Town of Monterey, Virginia
Approx. Scale 1" = 20'-0"
JJCM 1989

EXHIBIT B

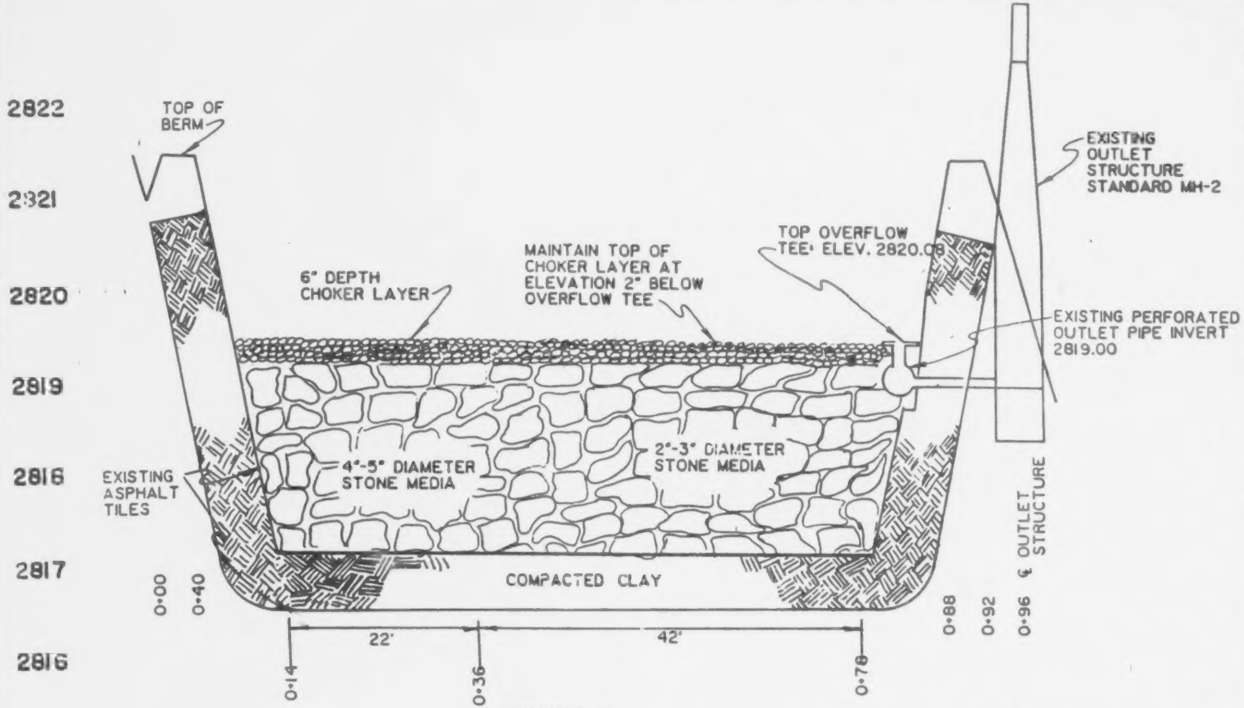

2822
2821
2820
2819
2816
2817
2816
TOP OF BERM
6" DEPTH CHOKER LAYER
MAINTAIN TOP OF CHOKER LAYER AT ELEVATION 2" BELOW OVERFLOW TEE
TOP OVERFLOW TEE ELEV. 2820.08
EXISTING OUTLET STRUCTURE STANDARD MH-2
EXISTING PERFORATED OUTLET PIPE INVERT 2819.00
EXISTING ASPHALT TILES
4"-5" DIAMETER STONE MEDIA
2"-3" DIAMETER STONE MEDIA
COMPACTED CLAY
℄ OUTLET STRUCTURE
0+00
0+40
0+14
22'
0+36
42'
0+78
0+88
0+92
0+96

FIGURE 5

SECTION AA

ROCK FILTER CROSS SECTION

NOT TO SCALE

ELEVATION SUMMARY

TEE OVERFLOW 2820.08
TOP CHOKER LAYER 2819.91
TOP STONE LAYER 2819.41
NEW POND FLOOR ELEV. 2817.41
EXISTING POND FLOOR ELEV. 2816.50

EXHIBIT C

EXHIBIT C

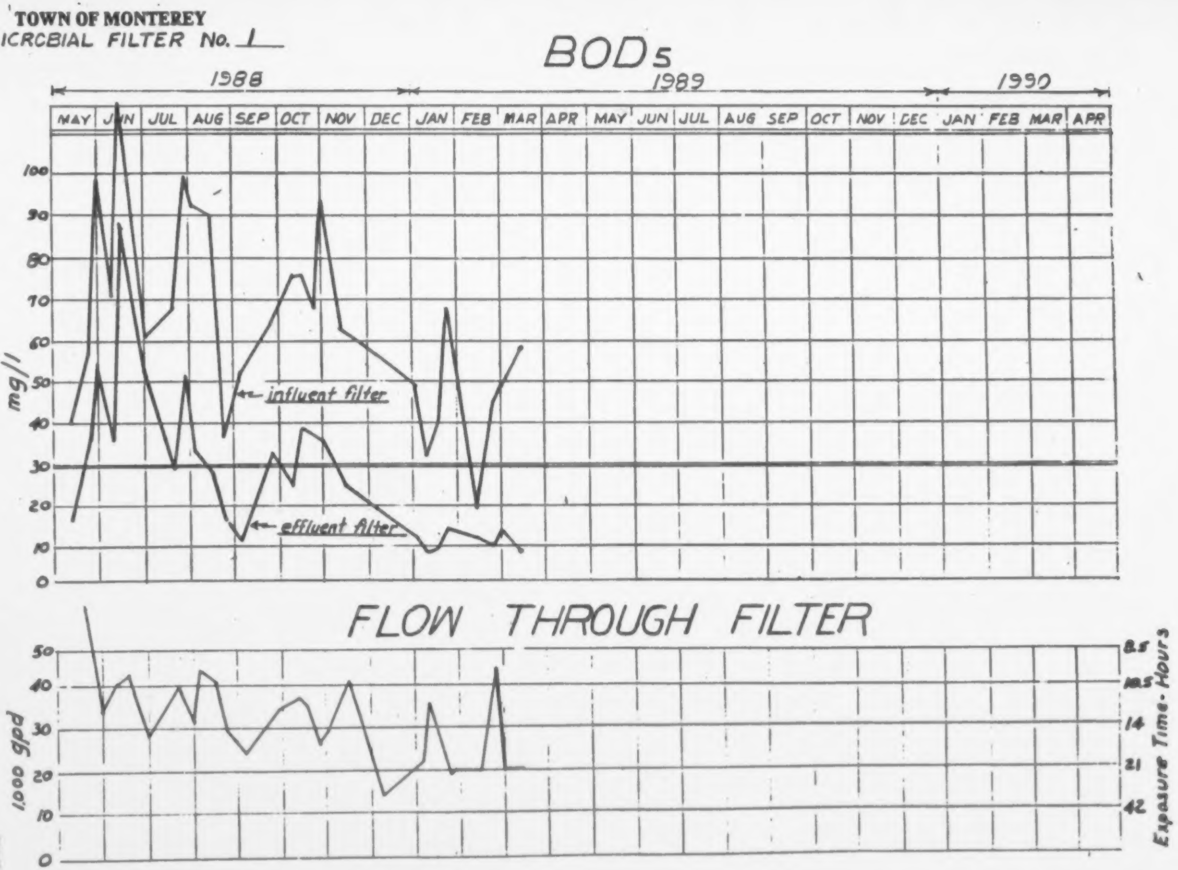


EXHIBIT D

EXHIBIT D

TOWN OF MONTEREY
MICROBIAL FILTER No. 1

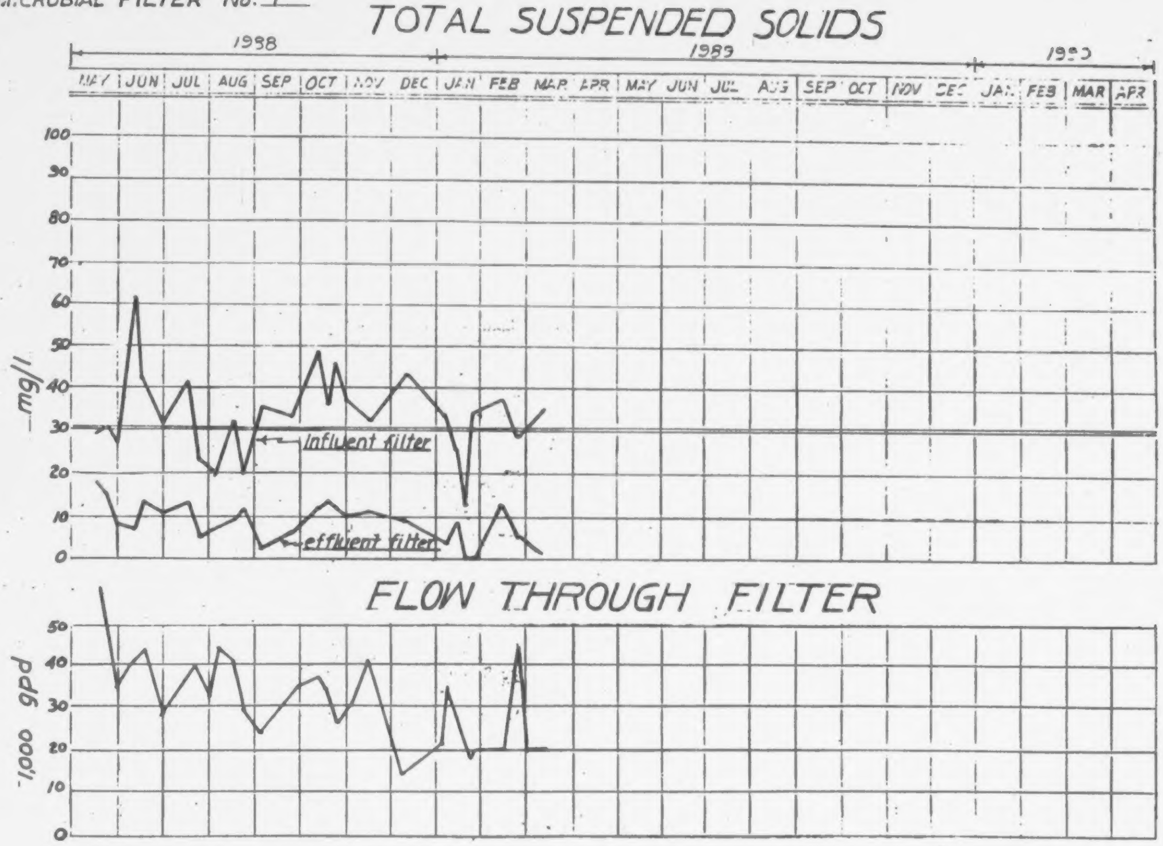
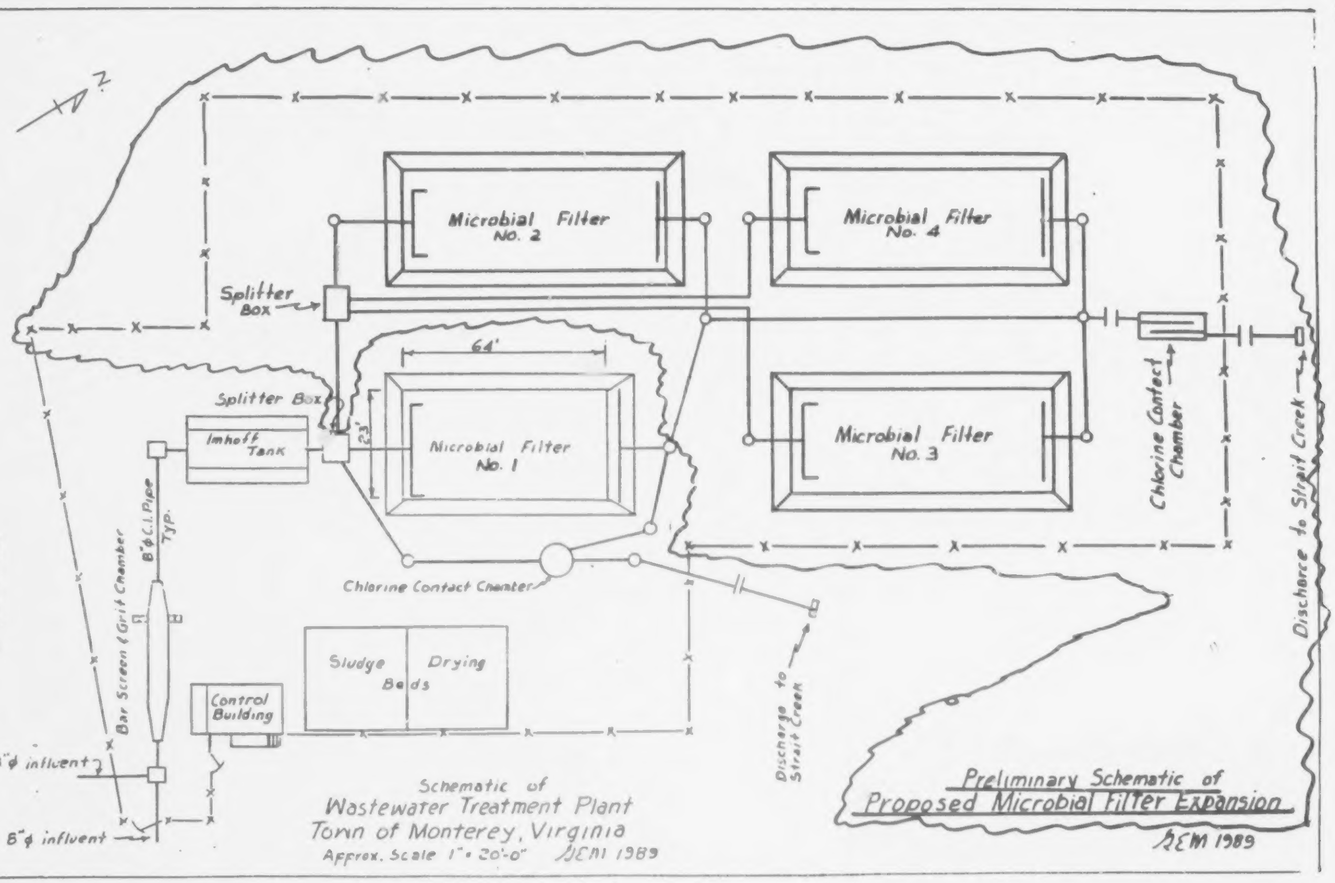


EXHIBIT E

EXHIBIT E

EXHIBIT F



N
Splitter Box
Splitter Box
Microbial Filter No. 2
Microbial Filter No. 4
Microbial Filter No. 1
Microbial Filter No. 3
64'
23'
Imhoff Tank
Chlorine Contact Chamber
Chlorine Contact Chamber
Discharge to Strait Creek
Discharge to Strait Creek
Bar Screen & Grit Chamber
8"⌀ C.I. Pipe Typ.
8"⌀ influent
8"⌀ influent
Sludge Drying Beds
Control Building

Schematic of
Wastewater Treatment Plant
Town of Monterey, Virginia
Approx. Scale 1" = 20'-0" REM 1989

Preliminary Schematic of
Proposed Microbial Filter Expansion
REM 1989

EXHIBIT F

Mr. **Packard**. Thank you.

Mr. **Nelson**. Thank you, gentlemen. I appreciate it very much. Mr. Rose?

Mr. **Rose**. I have just been informed that Dr. Forrester, who was going to discuss the Excimer Laser, has missed his airplane and he will not be here. But it is an application, the ability to use lasers in treating people with blockage that now requires a fairly expensive and it could be extremely dangerous surgery for bypass purposes.

One day just simple surgery using a laser to dissolve that blockage is going to become a reality and the question is getting a laser that is safe. And I believe we are on the track there and I'm sorry he is not going to be here, but it is a definite application of NASA technology.

Mr. **Nelson**. Let me just say a little personal comment here:

If this technology is perfected so that they can get the laser to zap the plaque without harming the artery wall—and, as I understand it, in a number of medical centers across the nation they have actually performed this procedure on arteries in a foot or leg—and if it is perfected, when it can do this just think of the billions of dollars that could be saved that is now spent on heart bypass surgery.

Mr. **Rose**. That is correct. No question.

Mr. **Nelson**. Not even to speak of the lack of trauma to the patient, where they don't have to open up the body cavity to go in to do the heart bypass operation.

Mr. **Rose**. That's correct.

Mr. **Nelson**. It's extraordinary. And run a tube in your groin through the vein, through the blockage, I take it?

Mr. **Rose**. That's correct, and then you just supply the laser beam and it will actually just—it actually just dissolves the material and evaporates it, just like that.

Mr. **Nelson**. And the patient walks out that afternoon.

Mr. **Rose**. That's correct.

Mr. **Packard**. Mr. Chairman?

Mr. **Nelson**. Yes.

Mr. **Packard**. It was not Dr. Forrester, but I have also been able to go to lectures on this technology where they do put a—just put a cathode, a very, very educated cathode with a laser at the end of the cathode and they can actually pinpoint where they want it to go and they simply just—it's just simply an auger, a laser auger that will just clean out the vessels and it will eliminate—even though we've had very good success with bypass surgery in recent years, it will essentially eliminate the need for bypass surgery and, of course, it will do a lot of other things that relate to other arterial-venal system problems. It has remarkable application—

Mr. **Nelson**. That's correct.

Mr. **Packard**.—a great, great future.

Mr. **Nelson**. And this was developed, I understand, at JPL originally?

Mr. **Rose**. Yes, I think it is.

Henry, do you—Yes.

Mr. **Nelson**. At JPL.

But now, as I understand it, the application is not necessarily with the Excimer Laser, it is going on to other kinds of lasers?

Voice: That's correct.

Mr. **Nelson**. All right. Space technology marches on.

All right. Let's have the next panel. We're going to hear from the fire fighters.

Mr. **Rose**. Correct. It says Chief James Manahan of the New York Fire Department Safety Battalion of the City of New York.

Chief, we're glad to have you with us.

STATEMENT OF CHIEF JAMES MANAHAN, NYFD SAFETY BATTALION, NEW YORK CITY FIRE DEPARTMENT, NEW YORK, NEW YORK, PRESENTING A FIRE FIGHTERS' BREATHING SYSTEM

Mr. **Manahan**. Mr. Chairman, members of Congress, I would first like to say that the fire fighters' breathing system was developed by the Johnson Space Center, by the Crew Systems Division for the lunar walk.

Back in the early Seventies we had a catastrophic period of time where America was burning and nobody was the wiser, we were losing block upon block of housing units. It came to light by a Swedish company, a film company that produced a film, The Bronx Is Burning. The Borough of Brooklyn was burning, too, but we didn't have the right publicity.

Public Technology, Incorporated, that municipalities throughout the country joined, it was solving municipal problems, approached the Fire Service and said what is your greatest need?

And at the time the Fire Service said that breathing apparatus, which was the main killer and maimer of fire fighters throughout the country, was one of the greatest problems we had. At the time, we were using an SCBA that weighed approximately 34 pounds. Fire Fighter Beach will show you what we were using back in the Sixties, Fifties—in fact, from the 1940's. This regulator was developed when the pilots flew over the hump from the Burma-China runs.

This unit is quite heavy, quite cumbersome, it puts all the weight on the shoulders. The regulator is chest-mounted. As you can see, the strapping is quite cumbersome to get on.

[Product demonstrated.]

Mr. **Nelson**. And this was used up until what year?

Mr. **Manahan**. 1975.

There were modifications made from the picture in the books that were distributed of the facepiece, but this was the facepiece that was used. That's a steel cylinder.

The technology was advanced by NASA to reduce the profile, to reduce the weight, to increase the duration and it also had to serve the needs of the country. Each fire service throughout the country has its own regional needs. What's good in San Diego is not too good up in Alaska.

So they came up with the fire fighters' breathing system, which reduced the weight by over 10 pounds. This unit weighs 23 pounds. It is a composite cylinder, an aluminum shell with a fiberglass wrap. It's called the Polar wrap, because it goes over the ends of both cylinders. This was the original NASA design of the cylinder.

[Product demonstrated.]

At the time of development, we were using a demand-type regulator. When you inhaled, you would create a slight negative pressure, the air would be injected into the facepiece and it would give the fire fighter the air he needed to breathe.

Later developments under OSHA required that we supply positive pressure, which would maintain a positive pressure inside the facepiece so that any leakage would be outborne and not inborne.

There's 4500 psi of air in that cylinder. It was rated during the current time to 1970 that a user would use 40 liters per minute and therefore give us a 30-minute rated cylinder.

But under actual fire fighting conditions, we found that the fire fighters with 70 to 100 pounds of equipment on them during a fire fight were utilizing between 100 and 140 liters of air a minute. This substantially cut down on the usage time. We approximately got 11 minutes of actual fire fighting use out of the development of the SCBA, which we had to require 20 to 25 percent of exit time for the user to get out of the hazardous atmosphere.

The original NASA design I told you was polar wrapped. When the system went commercial, the design feature came out that they had a hoop wrap, they would wrap the fiberglass composite around the axis of the cylinder and increase the thickness of the aluminum shell on the ends.

In 1984, we had a violent rupture of this type cylinder and the Department of Transportation put all of these cylinders out of service. We were in near catastrophic conditions, we were evaluating everything we had, we were pulling these old steel cylinders out for necessary planning.

The engineers came up and the Department of Transportation approved the insertion of a stainless steel ring around the neck of the cylinder and we reduced the air pressure to 4000 pounds, so further tests could be made and, in this way, kept the fire service in business.

While this technical advantage was going on, the technical advantages in the building industry and the chemical industry and the plastic industries went on. We've got high rise buildings with core design which puts unlimited space around core design of a building. Eleven minutes is not sufficient time to fight a high rise fire, so we went to larger cylinders: 45-minute cylinders, one-hour cylinders. These were all pro rated on the usage of 40 liters of air per minute, which we know didn't work out.

Recently in Los Angeles we had a high rise fire where we had four floors of a high rise building totally involved, which it took 40 percent of the on-duty personnel in Los Angeles to fight this fire. They had to recharge 400 cylinders; they used 400 cylinders during this fire fight.

In New York, we sustained a fire with the advent of the PCB covering in the Telephone Company fire where we actually used 1200 cylinders during one fire fight. Currently in New York we are now recycling over 100 cylinders each year.

Mr. Nelson. Is there a space application of updating the technology?

Mr. Manahan. Yes, there is. We would like to see the technology advance to a wireless radio system. That is one of the problems with wearing a facepiece; it interferes with the fire fighters' communications and verbally and radios. Radios were designed not for the fire service but for the police service and we adapted them.

We would like to see a wireless radio system built into it. We would like to see further development into the reduction of weight and size; longer duration. We would like to see the plastics used in the facepiece be less susceptible to scratching, which interferes with the vision of the firefighter. We have difficult time seeing through smoke as it is. We're not the Hollywood type of fire fighter where everybody walks in; we're crawling, going in on our bellies, we're getting covered with debris; we have a lot of water vapor coming back in our faces from steam and we really do take a physical beating.

[The prepared statement of Mr. Manahan follows:]

81

Manahan
#9

F.D.N.Y.

FIRE DEPARTMENT
CITY OF
NEW YORK

JOSEPH F. BRUNO
FIRE COMMISSIONER

HOMER G. BISHOP
CHIEF OF DEPARTMENT

NASA - BENEFITS ACHIEVED BY THE FIRE SERVICE

The fire service, both paid and volunteer departments throughout the country have been beneficiaries of the space program and its spin offs. Two of the most notable benefits were the development of the Fire fighters breathing system and the current project fires program.

During the sixties, the fire problem facing the country was developing at epidemic proportions. The cost factors were immeasurable and the housing stock of the inner cities was being decimated. The country is still feeling the effects of the destroyed housing units with its current homeless problem.

In 1970, Public Technology,Inc.,(PTI) a Washington Based firm responded to the needs of municipalities throughout the country by holding a national conference at the Kennedy, Space Center. It was during this conference that the need for an improved breathing system for fire fighters was considered the number one priority. NASA was uniquely qualified to marshall the expertise needed to carry out a program of development for an improved firefighters breathing system because of the experienced gained during the development of life support systems for luna exploration missions.

In order to ensure that any development efforts answered the need of the fire service, and that the new equipment would be acceptable from a budget and operational standpoint, PTI with support from NASA, assembled a User Requirements Committee composed of fire service professionals and city administrators to advise and guide the developmental efforts, they were from the cities of Los Angeles, California, Rochester, N.Y., Rockville Maryland, Chicago Ill., Orange California, Lexington Kentucky, Houston Texas, New York N.Y., Wheeling West Virginia, Boston Massachusetts, Dallas Texas.

The User Requirements Committee provided a set of performance requirements for firefighters breathing systems and helped the design engineers evaluate various concepts to best meet the design goals. Several alternative technologies were explored before choosing open loop compressed air. NASA presented to the panel the various alternatives for providing firefighters with breathing air.

The committee evaluated the advantages and disadvantages of each proposed system in light of firefighting needs and priorities. The committee considered such variables as duration, cost, ease of maintenance and interface with current protective clothing.

The system ultimately chosen was an open loop demand system. The User Requirements Committee determined that this configuration would most closely meet the fire service requirements for the vast majority of fire situations faced at this time.

Prototype units were developed and tested in the following cities, Houston Texas, Los Angeles, Cal., and New York City. Close liaison with the testing fire departments was maintained by NASA throughout the testing program. The objective of the field test program was to verify the performance of the firefighters breathing system under actual firefighting conditions in a wide variety of use and climactic conditions. The field test program was used to define areas of additional improvement. Retrofit and re-design necessary to correct any performance deficiencies found during the field test program was performed. Collectively the field test sites cover a wide range of occupancies from single family to heavily industrial. Extensive data for type of fire, time, conditions, use etc were maintained. The test companies found that the clear chest area and decreased profile of the unit allowed them to maneuver in ways impossible with current equipment. They could travel inside fire escapes, pass between wall studs, and enter or egress from casement windows. Visibility and communications, though still far from ideal, were greatly improved from the current equipment that was in use.

On completion of the field tests, the information gathered was made available to private firms and the fire fighters breathing system became a reality in the commercial sector.

The second benefit derived from the space spin off program was protective firefighting clothing developed at the Huntsville Ala. Space Center. the program known as Project Fires utilized space technology in material and design that was developed for space suits and the luna walks. The two most notable materials were nomex and kevlar. Kevlar strapping is now utilized on the Self-contained Breathing Apparatus now in service in New York City. The Protective clothing field tests are currently underway. Preliminary findings are positive.

The benefits derived from the space program, brought the fire service from the stone age to modern times, but there is a need for continuing the research and technology gleamed from the space program and to utilize this information for the benefit of the fire service throughout the country.

FUTURE NEEDS

The use of breathing apparatus in the fire service was greatly increased with the development of the Firefighters breathing system, and with its increased use a need was seen for further improvements. Notably, longer duration SCBA, further reduction in weight, improved visibility, and better communications.

The technical break throughs in building construction, man made fibers, plastics and the chemical industry have made fire suppression more hazardous.

Building Construction

The development of light weight trusses, both wooden and metal have increased the possibilities of collapse during a structural fire. Fire Fighters must move swiftly into the seat of the fire before failure of the support truss. Currently a fire fighter weighs seventy to one hundred lbs. over his normal weight when he is dressed in his protective clothing and supplied with a SCBA and the tools necessary for fire suppression. With such weights, a fire fighter is slowed down considerably during a fire fight. Truss construction which was once limited to commercial occupancies, is now being utilized in private and multiple dwellings.

Hi-Rise Structures

With the development of the core type Hi-rise building, there have been numerous towering infernos through out the country. These type fires tax the local fire departments to their utmost. The SCBA now in use is limited to a rated air supply of 30 minutes, 45 minutes, or 60 minutes. These rated times are based on the consumption of 40 liters of air a minute. Firefighters during a fire fight consumed much more than the 40 liter a minute criteria. Tests conducted at the Division of Training, N.Y.C.F.D. showed that during exhaustive activities that are required during fire suppression, the user of the thirty minute rated SCBA gets an average of eleven minutes operational time with a five minute escape time.(see attached article). As the size of the cylinder is increased to get the needed air supply, the advantages gained in reduction in weight is lost and also the profile of the user is increased. The sixty minute cylinder is cumbersome, fatigue sets in earlier and delays the user in reaching the seat of the fire.

Hazardous Material Incidents

The current SCBA now in use has a interface problem with entry suits utilized in a Haz Mat Incident. If the SCBA has a mechanical deficiency, the user has a problem putting the emergency procedures into effect for safe egress. Incapsulated entry suits present difficulties with the current radio now being utilized in the fire service. The current SCBA presents a distinct communications problem for the user. The current radios now being utilized by the fire service were developed for police work and adapted by the fire service. Communications must be built into the SCBA for it to be effective for the fire service.

Visibility is another problem that slows down the fire fighter during the suppression stage of the fire fight. The accumulation of vapor (water) on the face piece of the SCBA along with debris from the fire building limit the users visibility and in his attempt to clear the face piece by wiping it clean causes scratching. This scratching further limits the users ability to see. Extreme climactic conditions effect visibility by causing fogging and/or icing on the faced piece.

Summary

The fire service would like to see improvements in the current self contained breathing apparatus as to decreased weight, reduced profile, voice amplification, wireless radio communications, built in personal safety system, scratch proof face piece, longer duration.

In order to achieve these goals, research should be conducted into mediums other than compressed air. i.e. rebreathers, liquid air.

The needs of a fire department depends upon its regional needs. There must be development in these regional needs. Urban and rural regions have different problems facing the local fire department. Climactic conditions also present a problem, the fire service in Florida has a need for equipment that can function in a tropical climate, while the state of Alaska has a complete opposite need. It is therefore necessary to have representation from the fire service from all sectors of the country contributing to such research programs.

UPDATE: SCOTT 4.5

Self Contained Breathing Apparatus

by JAMES J. MANAHAN

Battalion Chief, Safety Operating Battalion

From 1966 to 1974, the New York City Fire Department, under then Chief of Department John T. O'Hagan, conducted research in conjunction with the National Aeronautical and Space Agency (NASA) to develop a new mask for firefighters. The purpose of this joint effort was to eliminate some of the disadvantages of the standard Scott mask, i.e., weight, visibility, short duration, and inadequate air supply during heavy exertion.

The Scott 4.5 now in use has better visibility, is lighter, and the weight has been shifted from the shoulders to the hips. These 4.5's have the same duration, with greater air flow, than the standard Scott mask.

Field tests conducted in 1975-76 showed that the 4.5 mask was used for fifteen minutes or less, 81% of the time. And, in 96% of the time that the mask was used, the duration was adequate.

During recent tests conducted at the New York City Fire Academy, it was noted by the present Chief of Department, John J. Hart, that the operational time of the Scott 4.5, Self Contained Breathing Apparatus (SCBA), was being exhausted in a relatively short period of time. Further tests were ordered to determine the minimum, average, and maximum anticipated amount of time that the air in the masks would be expended under fire conditions.

Utilizing Fire Department field units, tests were conducted at the Division of Training. The Academy's Building #4, which simulates a tenement-type, Class 3 structure, was used as the site of the tests. Monitors were selected from the Division of Training, the Safety Division, the Mask Service Unit (MSU), the Safety Operating Battalion, and Scott Aviation. The team of monitors from the Fire Department was made up of battalion chiefs, company officers, and firefighters.

In all, there were four different types of tests that were conducted. The tests were broken down in the following manner:

- Test #1—Five man units, using charged 2½" hose.
- Test #2—Five man units, using charged 1¾" hose.
- Test #3—Four man units, using charged 2½" hose.
- Test #4—Two 5 man units, using charged 2½" hose.
  Two 4 man units, using charged 1¾" hose.

All these tests were designed to require extreme physical exertion. And further, Test #4 had the added factor of heat and smoke.

In all the tests, a fully charged line was constantly moved on the fire floor and to the floor above and below, until the alarm on each member's Scott sounded. As the individual member's alarm sounded, he was removed from the test. The remaining members were kept working until their alarms sounded and they, too, were removed from the test. Five different engine companies and one squad company participated in the tests which ran for approximately three weeks.

TEST #1

September 8, 1981—Extreme Physical Exertion. Two 5 man units were used: Squad Co. 1 and Engine Co. 36. All members were dressed in full fire protective equipment. Squad Co. 1 began the test. They hooked up to a hydrant that was 100′ from the fire building. The officer was informed that the entire 2nd floor was involved in fire, and to stretch a 2½" hoseline to the fire floor and extinguish the fire. The line was stretched and charged with water. Monitors were used to keep the line moving at all times.

After the entire 2nd floor was covered, the line was advanced to the 3rd floor. Upon reaching the 3rd floor, a burst length was simulated. Additional hose was pulled onto the 2nd floor. The burst length was removed, the line was reconnected, and water was started. The line was then advanced onto the 3rd floor. The entire 3rd floor was covered and the line was then moved down to the 2nd floor. The line was kept in motion until the officer was the only one remaining whose warning device had not sounded. At this time, he was ordered to make a search of the building until his warning device sounded. The members of Engine Co. 36 repeated the same scenario.

At 1330 hours, Engine Cos. 93 and 263 reported to the test site. Engine Co. 263, a four man unit, was assigned a fifth man and ordered to duplicate the test taken by the members of Squad 1 and Engine Co. 36. Members of this unit, however, were instructed to remove their facepieces and shut down their cylinders on the sounding of their alarms. When all members' warning devices had sounded, the unit was told that they were trapped above the fire and beyond the reach of the aerial ladders on the scene. They were informed that they had to wait for 100′ aerial ladders that were responding to the scene. They were also informed that the atmosphere was to be considered toxic and that life could not be sustained without SCBA's. They were instructed to control their breathing rate for optimum usage. (Members stood still, exerting no physical effort, and employed controlled breathing. Figure #1.)

The members of Engine Co. 93 were put through the same operational tests as the three previous companies. They were instructed to remove their face-

TEST #1 — P.M.

Company	Member	PSIG In Cylinder	Duration At Alarm/Minutes Operational Time	Duration From Alarm/Minutes (Controlled Breathing)	Regulator
E.263	Officer	4,350	14:51	14:12	4.5
	Nozzleman	4,350	8:30	16:22	4.5
Five	Backupman	4,400	9:40	5:20	2.2*
Man	Doorman	4,350	14:51	16:03	4.5
Unit	Controlman	4,350	10:54	24:20	4.5

Member	Age	Height	Weight	Outside Physical Activity
Officer	49	5'8"	200	Softball
Nozzleman	26	5'6½"	133	Jogging
Backupman	28	5'11"	170	Jogging
Doorman	32	5'8½"	175	—
Controlman	40	5'8"	193	—

	Member	PSIG In Cylinder	Duration At Alarm/Minutes Operational Time	Duration From Alarm/Minutes (Controlled Breathing)	Regulator
E.93	Officer	4,400	14:00	6:45	4.5
	Nozzleman	4,400	9:45	7:40	4.5
Five	Backupman	4,350	8:20	10:02	4.5
Man	Doorman	4,350	12:10	—**	2.2
Unit	Controlman	4,400	10:25	5:27	4.5

Member	Age	Height	Weight	Outside Physical Activity
Officer	39	5'7½"	145	Jog/Swim
Nozzleman	27	5'11½"	162	Jogging
Backupman	46	5'9½"	162	Swimming
Doorman	28	5'11"	200	Weightlifting
Controlman	52	6'0"	168	Swim/Bike

** 2.2 Regulator substituted for 4.5 Regulator.*

*** Member removed and reported missing.*

Figure #1

pieces and shut down their cylinders when their warning devices sounded. When all SCBA's were shut down, one member was removed to a lower floor. The officer was informed that "a member was missing on the top floor" and that SCBA's were required for the search. The remaining members redonned their SCBA's and instituted a search. At three minutes into the search, the member was located. At this time, a "May Day," imminent-collapse-message, was given and all members evacuated the building. On reaching the street, all members were kept moving at a fast walk until their SCBA's were totally out of air. (Figure # 1.)

TEST #2

September 17, 1981—Extreme Physical Exertion. As in Test #1, two 5 man units were used: Squad Co. 1 and Engine Co. 36. Also as in Test #1, full fire protective clothing was worn. This test was conducted to ascertain if there is a difference between the physical effort required of the firefighter when utilizing 1¾" hose, as compared to 2½" hose. If there is a difference, does the increased physical effort induce an increased breathing rate, thereby exhausting the SCBA's more rapidly? The scenario was repeated by these units with 1¾" hose, instead of the 2½" hose used in Test #1. Both company officers and two-thirds of the members who participated in this test were the same officers and members who participated in Test #1. The results showed that even though the smaller 1¾" hose was lighter in weight, more physical effort was exerted by both units while using this hose. The light weight of the 1¾" hose permitted the rapid movement of the line and, therefore, more area was covered. This rapid movement increased the breathing rate, and both units had a shorter operational time than they had with the 2½" line in the previous test.

TEST #3

September 17, 1981—Normal Operations. At 1330 hours, Engine Cos. 24 and 40 reported to the test site. This test was conducted to determine the effect on the SCBA's duration when four man units operate with 2½" hose and [illegible]re protective equipment. These units were given the same simulated fire problem as the five man units, and were instructed to conduct operations as they normally would. (Note: Both officers assisted on the line. Three members of Engine Co. 24 who participated in this test are marathon runners.) When the last warning device sounded on the SCBA's worn by the members of Engine Co. 24, they were instructed to search for a missing member. They redonned their SCBA's and instituted a search. At this time, another "May Day," imminent-collapse-message, was transmitted. The unit left the building. All members were kept running until their cylinders were empty. (Figure #2.)

TEST #4

September 24, 1981—Heat and Smoke. Two 5 man units were used: Squad Co. 1 and Engine Co. 36.

All members wore full fire protective clothing, and were instructed to employ 2½" hose. These tests were conducted using heat and smoke, simulating, as close as possible, real fire conditions. Units were given the same fire problem that they had in Test #1. The members of Squad Co. 1 had an average mask usage time of 13:12 minutes, while members of Engine Co. 36 averaged 15:45 minutes. The combined operational time averaged for this test was 14:28 minutes.

At 1330 hours, Engine Cos. 24 and 40, two 4 man units, reported to the test site. The same scenario was repeated, this time with the members utilizing 1¾" hose and full fire protective equipment. This was another test to determine if there is a difference in the physical effort that is required when using 2½" hose as opposed to 1¾" hose. Using 1¾" hose, the combined operational average time for this test was 14:27 minutes. When using 2½" hose, the same units' combined operational average time was 13:51 minutes.

SOME TEST "NOTES"

Prior to use, all 4.5 SCBA's were checked, and all cylinders were tested for capacity. This was done when the specific units reported to the test site. All cylinder pressures ranged from 4300 to 4400 psig.

In all, twenty-eight different masks were used in these tests. Each mask was checked by the MSU. In addition, before and after each test, each cylinder was checked and the pressures measured with a calibrated gauge.

A Scott 2.2 Regulator was substituted for a Scott 4.5 Regulator in several tests. The 2.2 Regulator provides a warning signal between 19% and 21.5% of cylinder capacity, or 375 to 425 psig. The 4.5 Regulator provides a warning signal between 20% and 25% of cylinder capacity, or 900 to 1125 psig. The 2.2 Regulator averaged 11:55 minutes, while the 4.5 Regulator averaged 11:45 minutes. This substitution was made to determine if a greater operational time could be gained by reducing the warning signal time. As can be seen, the difference is not significant and did not warrant the conversion.

CONCLUSIONS

- There are many variables that affect the user's air supply, i.e., age, weight, size, physical condition and lung capacity. According to previous studies that were conducted during the development of the NASA prototype, there can be as much as a 60% difference in the rate of use between various individuals. However, there was no one physical factor that could be documented as being causal for using more or less air with the SCBA.
- The position of each member in the stretching and operation of the hoseline appears to be the primary factor in determining how long the air supply will last. The air in the officer's SCBA lasted the longest, while the air in the backup man's SCBA had the shortest duration. (See graph, facing page.)
- Also noted was the amount of air remaining in the cylinder when the alarm sounded. Three different tests were conducted to determine the maximum/minimum time allowed for escape. In Test #1, the members of Engine Co. 263 tried for maximum duration by standing still after the warning alarm sounded. They averaged 17:44 minutes, with a maximum duration of

TEST #3

Company	Member	PSIG In Cylinder	PSIG At Alarm	PSIG Used	Duration At Alarm/Minutes (Operational Time)
E.40	Officer	4,300	1,200	3,100	12:15
Four	Nozzleman	4,300	1,250	3,050	10:41
Man	Backupman	4,300	1,000	3,200	9:29
Unit	Controlman	4,350	1,250	3,100	9:27

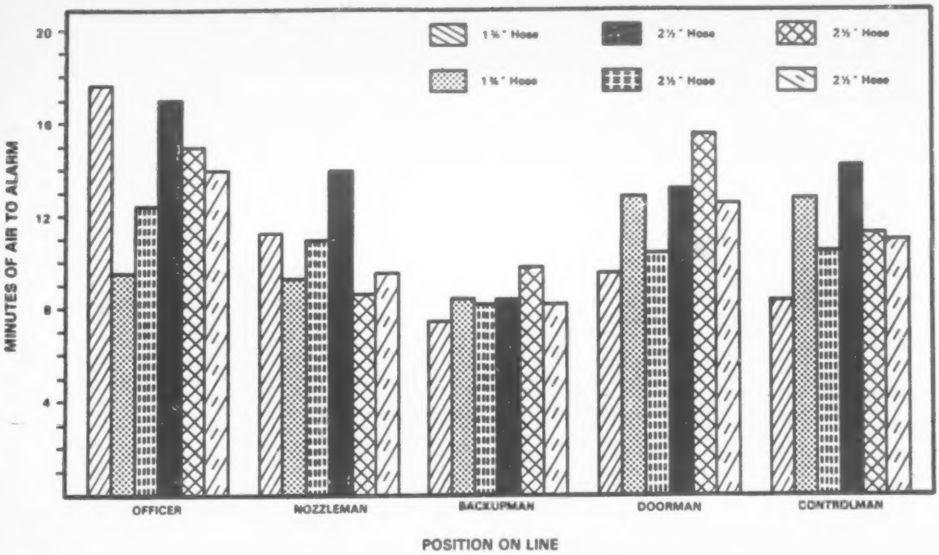
Member	Age	Height	Weight	Outside Physical Activity
Officer	44	5'8"	180	—
Nozzleman	38	5'9"	189	—
Backupman	29	5'9"	180	Swim/Bike
Controlman	32	5'8"	170	—

	Member	PSIG In Cylinder	Duration At Alarm/Minutes (Operational Time)	Duration From Alarm/Minutes (Running)	Duration Total
E.24	Officer	4,400	17:07	6:44	23:51
Four	Nozzelman	4,500	7:22*	6:04	13:26
Man	Backupman	4,400	9:15	4:02	13:02
Unit	Controlman	4,400	10:38	5:18	15:56

Member	Age	Height	Weight	Outside Physical Activity
Officer	42	5'8"	150	Runner
Nozzelman	35	5'8"	150	Runner
Backupman	35	5'10"	170	Runner
Controlman	47	6'0"	194	—

** High pressure gauge leaked when struck on door frame.*

Figure #2



24:20

20:42 minutes (Figure #1). This dramatic increase in maximum duration was due to controlled breathing.

The same test was carried out by the members of Engine Co. 93, except that those members were continually kept moving at a fast walking pace after their alarms sounded In this instance, the average time was 7:38 minutes, with the minimum at 5:27 minutes and the maximum at 10:02 minutes (Figure #1).

Once again, the same test was carried out, this time by the members of Engine Co. 24. In this test, Engine Co. 24's members were kept running after their alarm sounded. The minimum time on this test was 4:02 minutes, the maximum time was 6:44 minutes, and the average time was 5:32 minutes (Figure #2).

- Test #1 and Test #3 showed that the warning devices and the air supply reacted as designed (Figures #1 and #2).
- The overall average of operational time for mask usage for five man units was 11:45 minutes. For four man units, it was 11:48 minutes (Figure #3). Com-

(Continued on page 15.)

FIVE MAN UNITS

Position	Duration-High	Duration-Low	Duration-Average
Officer	18:07	9:30	14:51
Nozzleman	13:50	8:30	10:42
Backupman	13:09	7:06*	9:29
Doorman	15:11	9:01	12:07
Controlman	13:58	8:15	11:38

Overall Average
11:45

FOUR MAN UNITS

Position	Duration-High	Duration-Low	Duration-Average
Officer	17:07	12:15	14:32
Nozzleman	11:04	9:15	10:26
Backupman	19:01	7:22*	11:26
Controlman	14:07	9:14	10:50

Overall Average
11:48

** Leakage depleted air supply.*
(Note: Duration time represents operational time.)

Figure #3

cation. It has been reported that cardiac patients, so crippeld by the pain of angina that they could barely climb a flight of stairs, resumed a virtually normal life after undergoing surgery. And, nine out of ten times angina decreases significantly or disappears.

THE FASCINATING JOURNEY INTO THE HEART

The decision to have bypass surgey is made by the patient and his family in consultation with the physician and a cardiovascular surgeon. As with all operations, it is advisable to seek a second opinion. If your physician suggests bypass surgey, consult a heart specialist before agreeing to undergo the operation.

All surgery, whether minor or major, carries certain risks. In bypass surgery there is always a chance that the patient may suffer a heart attack while on the operating table. Or a clot may develop and move to the heart or brain. It is important to remember that a patient enters the operating room in the best possible condition, given the nature of his illness, and that precautions are taken to minimize the risks.

Heart surgery is a physically and emotionally draining experience for the patient. For this reason, patients about to undergo bypass surgery usually are admitted to the hospital two days before the operation in order to be tested and prepped for the procedure.

The patient is given a chance to become familiar with the surgical team and to ask any questions he may have about the procedure. And, in some hospitals the patient will be instructed on how to clear the lungs of mucus, coughing techniques, and deep breathing exercises to help the healing process after surgery.

Bypass surgery is a complex procedure involving great skill on the part of the surgeon and intense concentration by the surgical team. Bypass is really two operations: one on the patient's leg and the other on his heart. One or two incisions are made in the leg where the vein being used for the graft is removed. Another incision is made along the midline of the chest through the breastbone, and the ribs are held back to allow the surgeon access to the heart. During surgery, the patient's circulation and breathing are done by a heart-lung machine which allows the surgeon to work on a dormant heart.

The vein and coronary artery may be as thin as a pencil lead and, when drained of blood, are limp and fragile. They are delicate and hard to work with, and by draining them of blood they give the surgeon the degree of precision necessary for a successful graft. As many as twenty almost microscopic stitches may be needed to bind the vein and artery. The thread used for the sutures is as fine as hair, and the needles are ¼" long. A simple running stitch, the same kind used in dressmaking, delicately attaches the grafts to the coronary arteries.

The surgeon wears special headlights and magnifying glasses to facilitate his view of the minute coronary arteries. The sutures of the graft must be leakproof and are tested to determine if the connection can withstand the pounding of pumped blood. The procedure may take from two to six hours, depending upon the complexity of the surgery and the skill of the surgeon.

Although bypass isn't for all heart disease patients, this fascinating journey into the heart may give those with severe artery blockages, or medically untreatable angina, hope for an expanded life. ▲

(Update: Scott 4.5 SCBA continued from page 13.)

bining these times with the warning alarm times, it gives a minimum average time of 17:17 minutes for a five man unit, and 17:20 minutes for a four man unit.

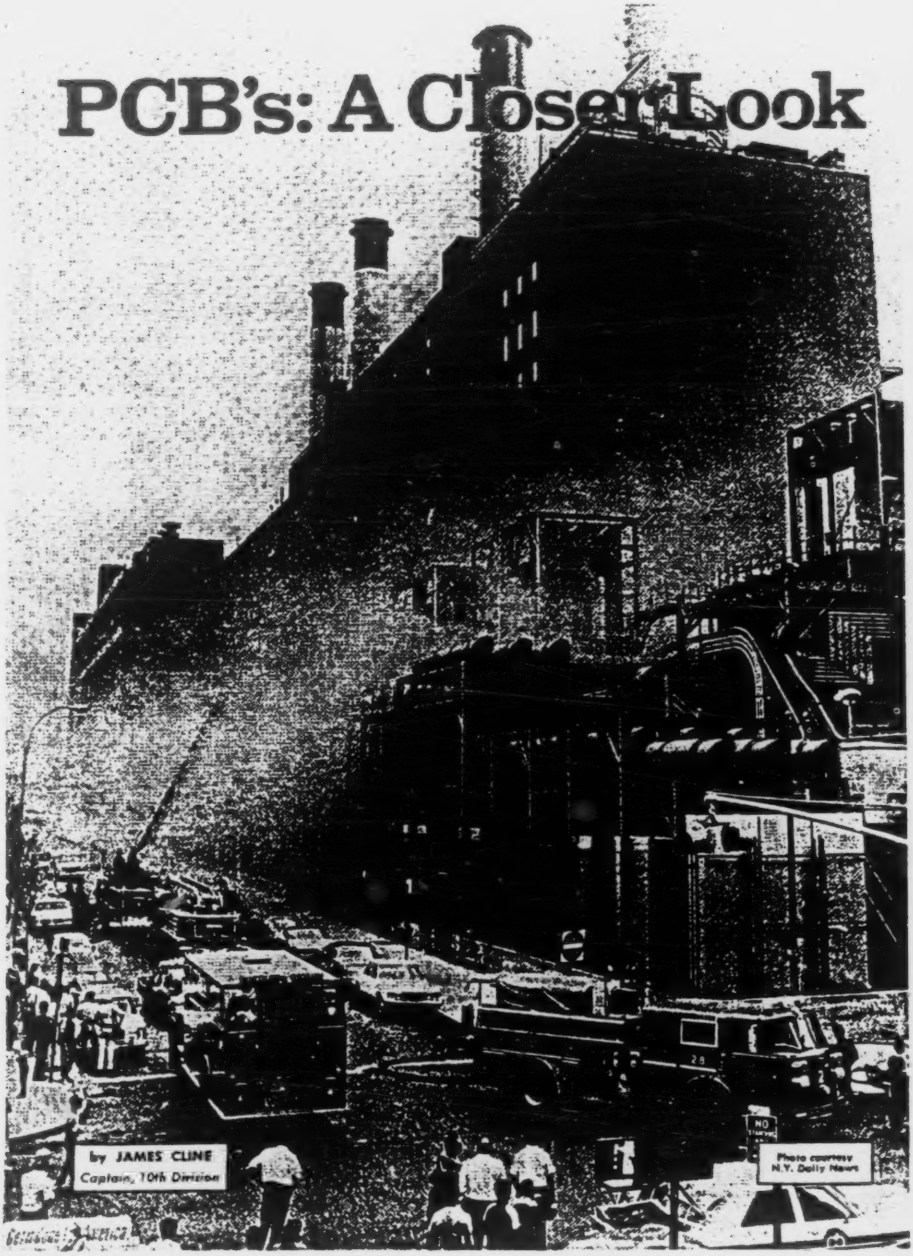
The Division of Training is currently researching and evaluating a method of controlled breathing in order to maximize mask cylinder usage. In addition, cylinders of one hour duration have been field tested to increase operational time for use at extended operations, i.e., subways, tunnels, high rise buildings, etc., and found to be suitable. Sixty one-hour cylinders have been ordered for use in long-duration operations.

- According to Training Bulletin—Mask #2, the rated time for a Scott 4.5 mask that is charged to 4500 psig, and is used under firefighting conditions, is twenty-two minutes. The training bulletin further states that the cylinder should be changed whenever the cylinder pressure drops below 2500 psig when not in use. Training Bulletin—Mask #2 has been changed to mandate that cylinders be replaced whenever the pressure drops below the full mark on the remote gauge (green area) when not in use. While in use, the cylinders are to be replaced when the warning device activates, or whenever the pressure drops below 1050 psig. (Note: Tests have shown that the daily mask check can be accomplished for at least eight days before the cylinder gauge moves off the full mark on the remote gauge.)
- The mask cylinders are presently charged to an average of 4350 psig. The MSU has made modifications on their charging system to ensure that a minimum of 4500 psig will be attained when a cylinder is charged.
- The rating on the Scott 4.5 mask has been changed from twenty-two minutes to seventeen minutes.
- Company officers should identify members who utilize large quantities of air under strenuous working conditions, and assign them to positions that are less arduous until their breathing habits are compatible to the required job performance.
- It is the responsibility of the company officer to see that respiratory equipment is used properly, maintained correctly, and inspected for proper operation. It is incumbent upon the company officer to establish controls that would ensure that the health and well being of his subordinates are not being jeopardized.

Based on the results of these tests, the Division of Safety concluded that the Scott 4.5 mask is suitable to meet the needs of the Fire Department for the majority of the fires encountered in New York City. With this in mind, the state of the art in SCBA will be continually monitored for future developments and technological changes. ▲

The Division of Safety would like to thank Chief of Operations Homer G. Bishop and Chief of Training Dudley M. Glasse for their wholehearted assistance. Their cooperation led to the successful completion of these tests. The Division of Safety would also like to take this opportunity to extend its thanks to the members of Engine Companies 24, 36, 40, 93, and 263, and to Squad Co. 1. The personnel who monitored these tests stated, "The members participating in these tests were taken to a point of near exhaustion, encountering conditions that were both difficult and demanding. They performed as true professionals and extended themselves accordingly."

40 story walk up with 70 to 100 lbs of equipment for each firefighter

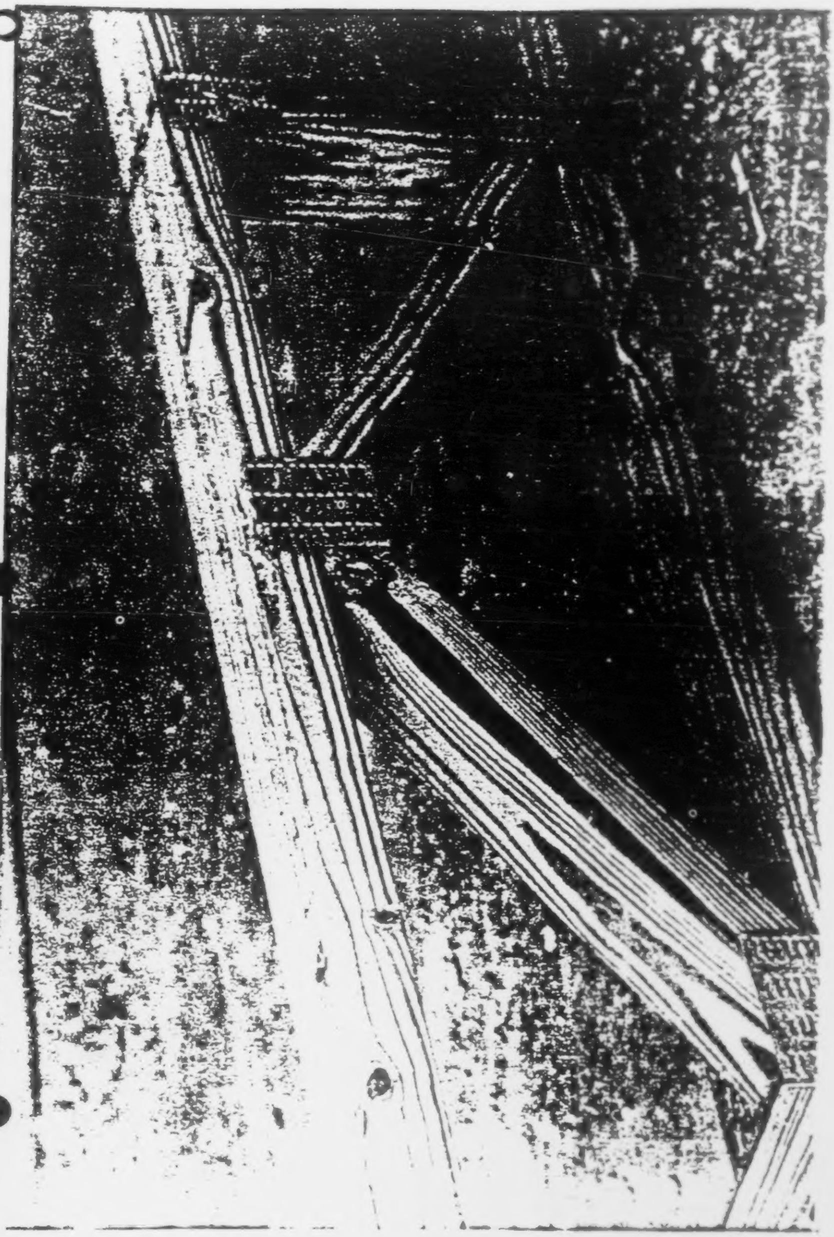


PCB's: A Closer Look

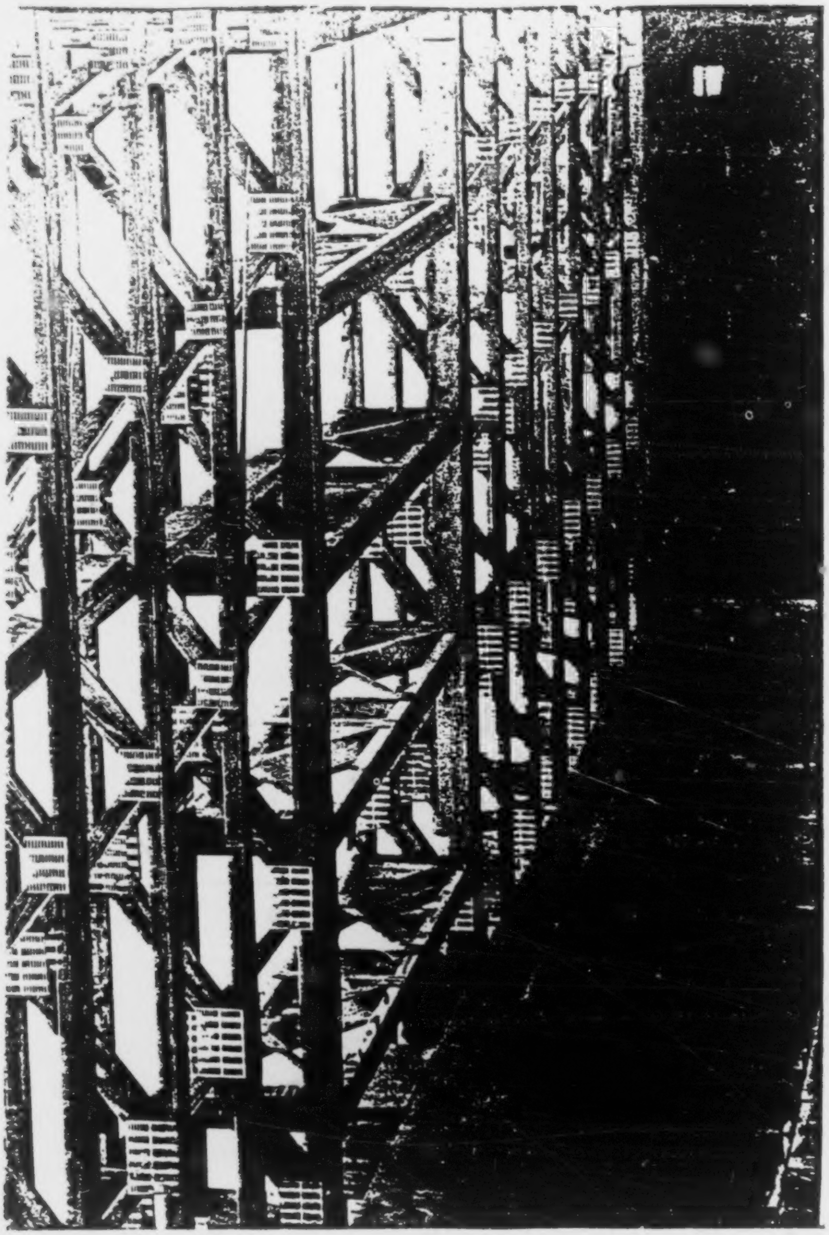
by JAMES CLINE
Captain, 10th Division

Photo courtesy
N.Y. Daily News

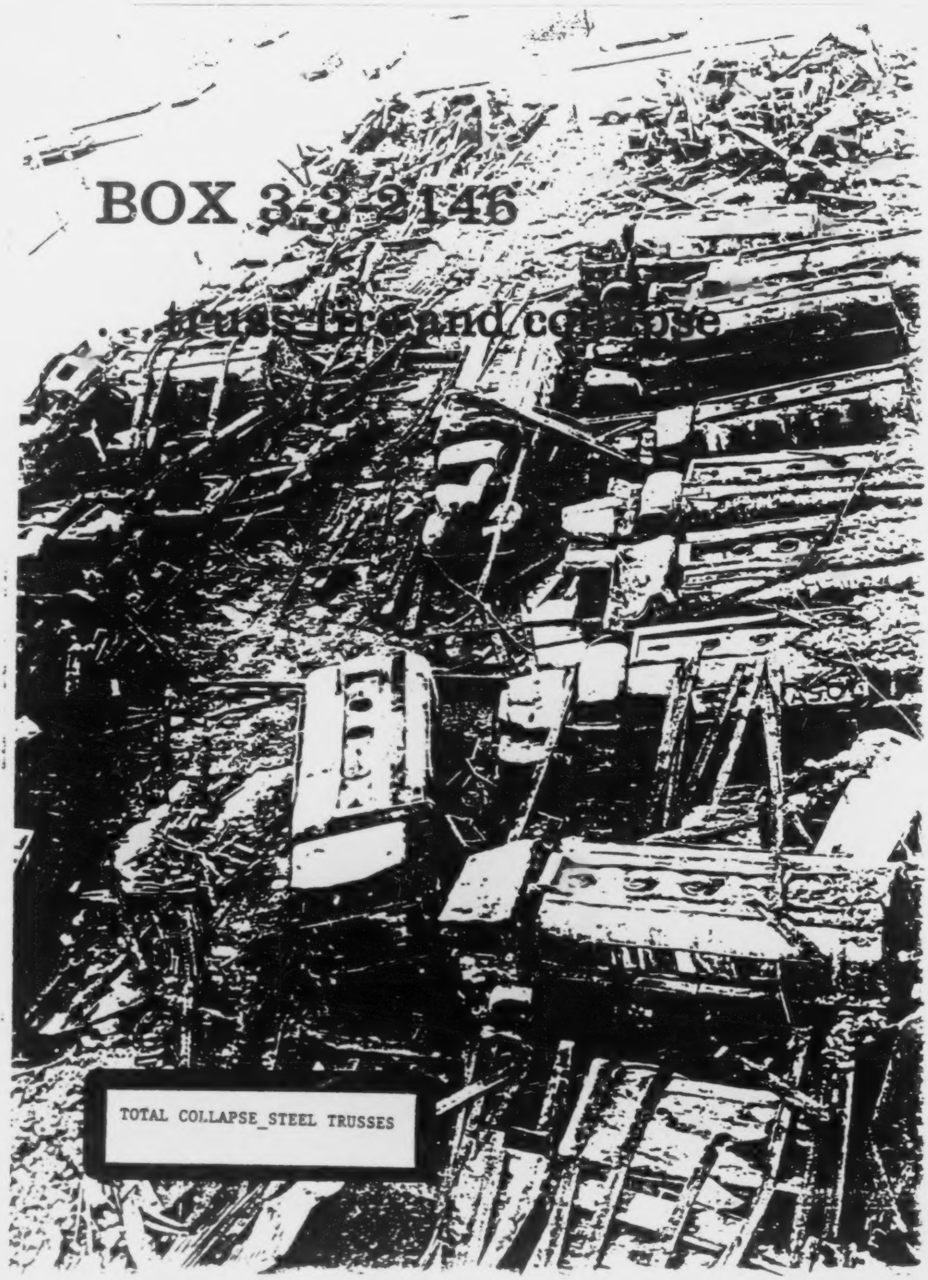
HAZ_MAT INCIDENT _ LONG TERM EFFECTS UNDETERMINED



WOOD TRUSS WITH GANG NAIL.



WOOD TRUSS CONSTRUCTION, BUILT IN LUMBER YARD WITH HORIZONTAL FLUES


BOX 3-3-2146
...truss fire and collapse
TOTAL COLLAPSE_STEEL TRUSSES

SCBA WITH STEEL CYLINDER AND RUBBERIZED FACE PIECE

RESUME: JAMES J. MANAHAN

PERSONNAL HISTORY: BORN - APRIL 25, L931
MARRIED, THREE CHILDREN
MILITARY SERVICE - ARMY SECURITY AGENCY

EMPLOYMENT: NYC FIRE DEPARTMENT, CAREER FIRE OFFICER
2/01/57 TO PRESENT

ASSIGNED LADDER CO. 9 UNTIL 1965

DIVISION ONE - 1965 - 1968

PROMOTED TO LIEUTENANT - ASSIGNED BATT 7 1968

ASSIGNED ENGINE CO 5 - 1969

PROMOTED TO CAPTAIN IN 1973
ASSIGNED TO DIV. OF FIRE PREVENTION -HI RISE UNIT.

ASSIGNED TO SQUAD CO. 4 IN 1974
TESTED FIRE FIGHTERS BREATHING SYSTEM DEVELOPED BY NASA. RECEIVED INTENSIVE INSTRUCTION IN THE USE AND MAINTENANCE OF SCBA′S.
INSTRUCTIONS NECESSITATED TRIPS TO THE JOHNSTON SPACE CENTER IN HOUSTON, TEXAS, DALLAS, LOS ANGELES AND DETROIT.

PROMOTED TO BATTALION CHIEF - 1976
ASSIGNED TO BATTALION 37. DESIGNATED BY BORO COMMAND TO ACT AS BROOKLYN COORDINATOR FOR SCBA′S

ASSISTED PROFESSOR PAUL DECICEO, BKLYN POLYTECH, IN THE BUSHWICK FIRE TESTS, PHASE 2 AND 3.

PARTICIPATED IN A PROGRAM AT THE STATE UNIVERSITY, STONY BROOK, N.Y. TO PROMOTE INTEREST IN THE ENGINEERING FIELD, FOR MINORITY CHILDREN, USING FIRE DEPARTMENT OPERATIONS, COMMUNICATIONS AND CHEMISTRY.

GUEST LECTURER AT STONY BROOK UNIVERSITY AND MERCY COLLEGE.

ASSIGNED TO THE SAFETY OPERATING BATTALION, JAN 1981.
PRIMARY RESPONSIBILITIES - SCBA AND FIRE OPERATIONS

EDUCATION:	HIGH SCHOOL GRADUATE
TRAINING:	FIRE DEPARTMENT INSTITUTE - 2 YEARS HYDRAULICS, CHEMISTRY, PHYSICS. COMPANY OFFICERS SCHOOL CHIEF OFFICERS DEVELOPMENT COURSE ARSON INVESTIGATION - JOHN JAY COLLEGE DISASTER INVESTIGATION, NYC DEPT. OF INVESTIGATION. INTERVIEWING TECHNIQUES AND IDENTIFYING ESSENTIAL ELEMENTS OF INFORMATION JOHN JAY COLLEGE BASIC, INTERMEDICATE, TECHNICAL AND ADVANCED CRASH MANAGEMENT - NYS DIV. OF CRIMINAL JUSTICE SEMINARS ON HAZARDOUS MATERIALS, LIFE SAFE CODE, HOTEL FIRES GIVEN BY NFPA.
MEMBER:	NFPA - FIRE SERVICE SECTION NYS FIRE CHIEFS ASSO NYC FIRE CHIEFS ASSO.
OTHER:	AUTHOR - WYYF, SCBA SAFETY EQUIPMENT INSTRUCTOR - DRIVER TRAINING SAFETY F.L.S.P. DISASTER MANAGEMENT TECHNICAL ADVISOR TO CORPORATION COUNCIL IN PREPARATION OF TORTS

Mr. **Nelson**. You know there are scratch-resistant sunglasses that have been made as a result of space technology and we're going to hear about those in just a minute.

Are there any questions or comments from the members?

[No response.]

Chief, we really appreciate you coming and sharing with us this information about how space technology applies directly to you. You're very kind.

Mr. **Manahan**. Thank you.

Mr. **Nelson**. Mr. Rose.

Mr. **Rose**. This is our last formal panel, it is presenting the Power Factor Controller to be used in energy conservation, Dr. George Halas—that's a fairly famous name—he's the Manager of the Sales Department, Nordic Controls Division, Furnas Electric Company, Batavia, Illinois.

Mr. Halas.

STATEMENT OF GEORGE HALAS, MANAGER, SALES DEPARTMENT, NORDIC CONTROLS DIVISION, FURNAS ELECTRIC COMPANY, BATAVIA, ILLINOIS, PRESENTING THE POWER FACTOR CONTROLLER

Mr. **Halas**. I thank you very much. I'm not the real George Halas, the real George Halas was my uncle, one of the founders of the National Football League, owner-coach of the Chicago Bears and what have you.

The Frank Nola National Aeronautics and Space Administration spin-off technology that I represent has given American industry the opportunity to increase production, to reduce maintenance down time, to lengthen equipment and tool life and to save energy.

Now if you think for a minute that we have hundreds of millions of electric motors in this country: the air conditioning coming in, the little slide projector here, 70 percent of all electric energy consumed in this country is consumed by electric motors. The NASA spin-off technology has found a way to save some of that energy.

And if you figure you have, say, an automotive plant that consumes—just one of many stamping plants for a large automotive manufacturer consumes a million dollars' worth of electrical energy per month. If you can save even a small portion of that, that's significant; if you can lengthen the tool life, if you can reduce maintenance down time, if you can lengthen the life of an electric motor, you can make American industry more competitive.

And that's what has happened. Frank Nola found a way to measure the load on an electric motor. What he did was he found a way that enabled him to continuously and automatically measure the load on that motor. If the motor is lightly loaded, he found a way to save energy.

We talked about diesel engines here. When you make a diesel engine, you take a casting and you bring it down, you drill, bore and tap it. When that spindle drive is drilling or boring, the motor is fully loaded. But when it's waiting for the next engine block to come down, it's lightly loaded. During that period of time then he can save energy.

And what we have done with that is we have added additional American technology: we now can take an electric motor and start it off softly. And I've got a demonstrator over there so in the walk-around period people can see that.

We can start an electric motor, take a 10,000 pound flywheel on a stamping press, bring it up to speed gradually without wearing the belts out, without any physical impact to the equipment. When it's up to speed, we can measure the load on that. If that stamping press is not stamping, it's waiting for the next piece of metal to come down, or if they are making an adjustment on a die on one of the other presses, then we can save electric energy.

The other piece of technology that we've added is we put a DC brake with it. If you have a 10,000 pound flywheel or you have a big radial saw, if turn it off because it's a big inertial load it will take that flywheel 20 minutes to come to a stop. With the spin-off technology which NASA developed and we further evolved into electronic braking, we can bring that 10,000 pound flywheel to a stop in 30 to 40 seconds. That means they can make a die adjustment and back into production without any wait.

If you just take one pressline in a large automotive plant, if that is down, that costs that automotive plant $80,000 an hour. If you keep that line down for, say, more than 11 hours, you shut the stamping plant down. This type of NASA spin-off technology has helped the lumber industry, not only in this country, but Canada—British Columbia is just going wild with this type of device.

So the NASA spin-off technology has given us the opportunity to save electrical energy. Seventy percent of all electric energy consumed in this country is consumed by electric motors. So this is a very significant development.

Mr. NELSON. Well it's quite exciting.

What was the original technology developed for NASA from which this spun off?

Mr. HALAS. Okay. This was the effort by Frank Nola and NASA,the George C. Marshall Space Flight Center, to save energy on electric motors. In other words, when you put something up into space and you have an electric motor, if it's fully loaded it needs full power. If it is lightly loaded, it doesn't need that much power. And that's the evolution into American industry.

Mr. NELSON. Was this developed at the time we were going to the moon or since then?

Mr. HALAS. This was actually invented in 1975 and NASA started to license American industry in 1979. This is just after the oil embargo when everybody was trying to save energy.

Mr. NELSON. Members of the Committee?

[No response.]

Mr. NELSON. Well this is exciting, and we're going—

Mr. ROHRBACHER. I just have one question.

How much money are we talking about saving here? Are we talking about billions and billions of dollars or is it—

Mr. HALAS. The possibility here: yes. If you take—and I keep sticking with an automotive plant because that is under very competitive pressure from off-shore manufacturers—if you take one plant, spending a million dollars a month, you can save anywhere from 5 to 14 percent of that. So it is a significant amount.

But some of the other things are that you extend the motor life. Because if the motor is not running at full voltage coming in, then the motor runs cooler. It extends that motor life. So there are many other ensuing advantages to this other than just the cost of electricity.

Mr. **ROHRBACHER**. Thank you very much.

Mr. **NELSON**. Well we really appreciate it, Mr. Halas. Thank you very much.

No, he cannot get you tickets to the Chicago Bears.

[Laughter.]

Mr. **HALAS**. I have them; if you call me, we'll see what we can do. Thank you much.

[The prepared statement of Mr. Halas follows:]

Fc

#10

United States House of Representatives

Committee on Science, Space and Technology

NASA Technology Spin-off Hearing

Date: Thursday April 13, 1989
Time: 9:30 AM - 1:30 PM
Place: Room 2318, Rayburn House Office Building

The Frank Nola, NASA, Energy Saver

Power Factor Controller Used In American Industry

Mr. George Halas
Manager, Sales Development
Nordic Controls Company
Division of Furnas Electric
1000 McKee Street, Batavia, Illinois 60510
800-323-5450

The Frank Nola, NASA, spin-off technology that I represent has opened the way for American industry to increase production, reduce maintenance, lengthen equipment and tool life, and save energy. It has helped to make American industry more competitive.

Good morning, I'm George Halas and I represent the Nordic Controls Division of Furnas Electric Company. Furnas Electric Company is a privately owned manufacturer of industrial electric motor controls with sales of over $100,000,000. Furnas Electric products, noted for high quality, are found in major industrial plants around the world.

In 1979, the Nordic Controls Division was founded by Furnas Electric Company to manufacture the energy saving, Frank Nola, NASA, Power Factor Controller, as a means of entering the solid-state control motor industry.

It was the Frank Nola invention and the NASA licensing of American indstry that gave great impetus to the then lethargic solid state motor starter industry. It was the NASA licensing of American industry that paved the way to save electric energy on existing production equipment. It was in this period, soon after the oil embargo, that this energy saving invention provided the spark needed to ignite the solid-state motor starter industry. Furnas Electric Company was one of the first licensees of the NASA, Power Factor Controller technology in 1979.

In the last ten years, Nordic has enlarged on the NASA technology and now leads the field in solid state reduced voltage starter and electronic braking.

In 1981, Lynn Johnson of Nordic Controls, augmented the NASA, spin-off technology and invented the first successful three-phase power factor controller. It was this invention from the NASA spin-off technology that really opened up the industrial market.

American industry is the direct beneficiary of the NASA spin-off technology.

The NASA spin-off technology and additional American technology has:

1. Increased production on existing tools and equipment;
2. Reduced maintenance and repair time;
3. Increased electric motor and equipment life;
4. Saved electrical energy;
5. Made American industry more competitive.

In an American automotive plant, for example, where the cost of electric power can exceed one million dollars per month, even a small saving can be significant. In one automotive plant, the Frank Nola, NASA, energy saving invention, has been measured at a 5 to 14% savings, depending on the particular application.

Three-phase, AC induction motors are the workhorse of American industry. From the basic, Frank Nola, NASA, single phase, spin-off technology, it was the Lynn Johnson three-phase power factor controller invention that really accelerated the industrial potential for American industry.

By automatically regulating the power to the motor, that is, giving the motor only the correct amount of electrical energy needed to do the job, energy is saved, the motors run cooler and last longer, and the equipment requires less maintenance.

I would like to illustrate this by briefly describing one specific application - one of the hundreds we have uncovered. Metal stamping presses in automotive plants are used to stamp out automobile parts including car and truck bodies. These presses typically have AC induction motors ranging up to 500HP. Once the motor has started and brought the flywheel up to running speed, it can run at idle currents until the actual clutch of the slide mechanism is engaged and only then is the motor fully loaded. Actual measurements of energy saved during these periods of running idle range from 5 to 14%. The power factor controller lowers the voltage to the motor during these idle periods of light loads, thus saving energy. The return on investment was attractive enough for at least one automotive company to begin a program of incorporating these devices in their stamping press controllers. The financial return on investment is a major consideration, but the efficient use of a limited energy resource is an issue of concern to us all.

The Frank Nola power factor, or energy saving invention, provided an automatic way to reduce the amount of energy consumed by a lightly loaded single-phase electric motor. The Lynn Johnson three phase invention provided a way to automatically reduce the amount of energy consumed by a lightly loaded three-phase motor and also provided a way to automatically reduce high incoming line voltage to the motor nameplate voltage. The motor nameplate voltage is the voltage at which where the motor was designed to operate most efficiently at full load. This line voltage limiting function also saves energy. These two functions combined to save more energy, make the motor run cooler and extend the life of the motor.

In the United States, some electric utilities may generate 480 volts plus 5 percent or 504 volts. This is done so that with the normal line losses, the customer at the end of the utility line will receive enough power to run his electric motor and other electrical equipment. The standard electric motor today is rated at 460 volts. Also, there are still millions of older motors in American industry rated at 440 volts. This means that if the industrial plant is located close to the generating station, or on a "strong" utility line, the motors could be forced to operate on 10 or 15% more power than they were designed to operate on most efficiently. This extra, unnecessary voltage, causes the motor to run hotter, shortens the life of the motor, and wastes energy. Also, the high voltage increases the motor starting torque and increases the physical starting shock to the entire equipment system and causes additional equipment problems.

In addition to the energy savings and line voltage limiting functions, Nordic has successfully incorporated other existing technologies - reduced voltage soft start and electronic braking. Now American industry can start a motor with reduced voltage, bring it up to speed without any belt slippage, save energy when it is running lightly loaded and bring the motor and flywheel to a smooth stop with electronic braking.

For example, let's take an automotive stamping press with a 10,000 pound flywheel. This press would be but one of six to eight presses in a press line. If any one of the presses is down for repair or stopped for a die adjustment, the entire line is shut down! Any change to the presses which can increase their production time and reduce maintenance down time is adding extra production capacity to the existing presses.
When an automotive punch press is started, using the old conventional, across-the-line method, the motor is subjected to full line voltage and six to eight times full load current inrush; therefore the motor tries to get up to speed faster than the flywheel and this results in the drive belt slipping, burning, and stretching. This hard, physical start is very tough on the punch press belts and the hard electrical start is very tough on the electrical system and other equipment in the area.

With reduced voltage starting, line voltage limiting, energy saving, and electronic braking, we see an entirely different picture. The reduced voltage starting gives the motor just enough voltage to get it started slowly and then ramps (increases) the voltage so that the motor comes up to speed smoothly without any belt slippage and limited physical impact to any of the equipment train. Once the motor is up to speed, the line voltage limiting automatically adjusts the incoming line voltage to the motor nameplate voltage. If the press is not striking metal (running at idle), then the energy saving Frank Nola, NASA, invention further reduces the voltage automatically to whatever is needed to keep the motor and flywheel turning at the proper speed until the next piece of metal is to be struck and the motor is again called upon to do work at full load.

Example:

Incoming Line Voltage measured at:	First shift - 497 volts Second shift - 514 volts Third shift - 526 volts
Line Voltage Limiting reduces the voltage to:	460 volts, 180 amps
Energy Savings further reduces the voltage to:	372 volts, 125 amps
When the press starts to strike the next piece of metal, the voltage rises in 8.3 milliseconds to:	460 volts, 229 amps
When the press is stopped for a die adjustment, the electronic brake stops the flywheel in 30 to 40 seconds	Without any belt slippage - smooth stop

When a stamping line starts on a new lot of steel and four or five die adjustments are required, you can easily see where the 20 minute coast-to-stop time would take several hours and all that production time would be lost. If the plant is producing 24 hours a day, seven days a week, there is no way this lost production can be made up. If the old mechanical brake was used to stop the flywheel, it still took four to five minutes and it soon wore out and the press and the entire press line was shut down for eight hours to repair the brake.

This example would be the same for a large radial saw, or a chipper wheel in a lumber mill, or a rock crusher in a stone quarry, or any application with a large inertial load that has to be started and stopped for tool replacement, die adjustment, or removal of jammed material.

This same Frank Nola, NASA, spin-off technology, combined with the Lynn Johnson invention and additions are now used in all facets of American industry and services. Your local water utility uses this on wells and pumps. The reduced voltage starting enables the water utility to start pumping from the reservoir to the pressurized water mains without developing the damaging, high-head pressure normally caused by the old, across-the-line, hard starting. With the soft start, the water pressure increases gradually and the surge rupturing of the water main is elminated. So when the pump is to be turned off, a Nordic controller can ramp (lower) the voltage so that the pump slows down and the water pressure decreases slowly, preventing damaging water hammer.

Every day we find yet a new and different application for the Frank Nola, NASA, spin-off technology or the Lynn Johnson invention and additions to this technology.

Attached is a partial list of some of these applications.

Are there any questions that I may try to answer?

Thank you.

Electrical Soft-Start

Industry	Problem Solved
Natural Gas Producer	Cooling Tower - Breaker
Asphalt Producer	Auto Transformers - Cool Down
Sheet Plastic Producer	Banbury Mixer - Electric Utility
Automotive	Mixing Box - Windmilling
Automotive	Computer Blow-out
Medical Center	Patients Solid-state Monitoring
Municipal Water Utility	TV Trauma
Automotive	High Pressure SV Lights
Mining Operation	Air Handlers in Tunnel Project
Forest Products	65 Fans, Sequence Start
Forest Products	Elec/Mech Contacts
Automotive	Stamping Presses

Physical Soft-start

Heavy Equip. Manufacturer	ASRS, Conveyor
Paint Manufacturer	Paint Filler - Mixer
Automotive	Pump
Commercial Building	Cooling Towers
Beverage Canning OEM	Can Seamers, Conveyors, Two Speed
Municipal Water District	Couplings, Seals
Personal Products Producer	Shampoo Pump, Stainless Steel Pipe
Food Producer	Pump, Plastic Pipe
Municipal Water Utility	475 ft., Hollow Shaft deep well
Municipal Water Utility	Check valve, Head Pressure
Forest Products	Check valve, Air valve, Plastic pipe
Automotive	Stamping Presses
Forest Products	Drying Kiln

Mr. Nelson. All right. Now we're going into the phase where we've got a hand-held mike and we're going to have, with a five-minute limitation, we are going to go to each of these presentations and we're going to have a presentation.

So Mr. Rose, go ahead.

Mr. Rose. Well I'm going to get out of the way and let each one of these presentations go and identify themselves and speak for five minutes, saying what it is the spin-off was. And if the people could kind of try to identify the NASA technology and how it was—what it was for and then how it was applied, we would appreciate that.

Thank you.

Mr. Nelson. Okay. Presenting the Robotic Sow, Eric Jarmain.

STATEMENT OF CULLUM JOHNSTON, FARMATIC, INCORPORATED, LONDON, ONTARIO, CANADA, PRESENTING THE ROBOTIC SOW

Mr. Johnston. I'm replacing Eric Jarmain, my name is Cullum Johnston, Mr. Chairman, and Committee members.

A swine farm in rural Iowa may seem a long way away from a NASA laboratory, but innovative equipment relies on technological advances in science to make them both practical and reliable. Such is the case with the Robotic Sow. It is a revolutionary machine that will nurse baby piglets when the mother sow is either unwilling or unable to perform that task.

On a hog farm, pre-weaning mortality is a serious problem, with between 15 and 25 percent of all piglets dying before they're three weeks of age. And fully three-quarters of that death occurs within the first three days of life.

Over the years, many devices have been developed to replace the sow but in the most part have failed for a number of reasons: first of all, the device did not adequately simulate the real sow's functions; the mechanical and electrical components were too complex for a barn environment; and the devices did not take into account the specific behavior patterns and requirements of baby pigs, and also the nutritional requirements were not adequately developed at that point.

To overcome these, a researcher in animal behavior, Dr. Frank Hurnik, spent seven years with a team of researchers deciding what the important factors were in animal nursing and, in particular, piglet nursing.

Farmatic of London, Ontario, became involved in the project because of our expertise in the development of new technology in agriculture, but we found that if we used conventional systems for this particular type of equipment that we would not be able to be successful. The numbers of moving parts have to be kept to a minimum in a harsh, swine barn environment.

A particularly difficult aspect of the project was overcome because of work done on the NASA space program: to maximize its quality, the milk has to be kept refrigerated, and obviously, using conventional technology with motors, coils and freon, there's many, many parts to fail in a harsh corrosive barn environment.

The Robotic Sow's electronic refrigeration system uses the Peltier cell developed by NASA for satellite cooling. These compact heat pumps have no moving parts and are about the size of a box of matches.

The Robotic Sow is a magical unit. Everyone who sees it operate is instantly captivated by the blue plastic mother that calls its piglets by means of digitized grunts—

[Laughter.]

Mr. Johnston.—which we will demonstrate to you later.

Mr. Nelson. Mr. Nagle, you're from Iowa—

[Laughter.]

Mr. Nelson.—can you give us a rendition?

Mr. Nagle. You, obviously, people don't know how to call hogs—

[Laughter.]

Mr. Nagle.—but the basic word is soooee, but it's said much sharper, louder than that. But I would be interested in your interpretation.

[Laughter.]

Mr. Nelson. I leave it up to the machine.

Mr. Nagle. By your accent, I can tell you're from Iowa.

[Laughter.]

Mr. Johnston. The device is a result of scientific innovation that would have not been possible nor feasible if it wasn't for the work of NASA and other researchers. Even though we are from Canada, I'd like to point out to members of your Committee that we buy products from a California company, and so we indirectly benefit from your space program.

Mr. Nelson. You also are very much a part of our space program. You're going to be a major participant on the space station, with the robotic arm.

Thank you, Mr. Johnston.

Mr. Johnston. Thank you.

Mr. Nelson. Well we're looking forward to this demonstration and I want to hear those digitized grunts.

[Information referred to follows:]

REPORT TO THE U.S. HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY.

NASA FY90 AUTH
SA
RING 4/13/89
T NO 69

Thursday April 13th 1989.

Mr. Chairman, Committee Members,

A swine farm in rural Iowa may seem far removed from a NASA laboratory, but innovative equipment relies on technological advances in science to make them both practical and reliable. Such is the case with the Robotic Sow, a revolutionary machine that will nurse piglets from birth to weaning when their natural mother is unable or unwilling to raise them.

Preweaning mortality is a serious economic problem for hog producers. The majority of hog producers lose between 15% and 25% of their piglets before they are weaned. Reports show that 71% of this mortality occurs in the first three days, with half of it occuring during the first day.

Over the years, many surrogate sows have been developed and have failed in the marketplace. The piglets did not thrive on these machines for a number of reasons:—

* the nursing units did not adequately simulate the natural nursing process and abnormal behaviour, such as tail biting, ear and navel sucking became a problem.
* the mechanical and electrical components were too complex and simply would not perform in a barn environment.
* the design of the nursing devices did not take into account the behaviour of piglets and thus were not sanitary nor sturdy enough.
* milk replacer technology was not advanced enough to adequately duplicate the nutritional value of sow's milk.

To overcome these problems, Dr. Frank Hurnik, an expert in animal behaviour, along with a group of dedicated researchers, spent seven years investigating the many factors which affect a piglet's behaviour whilst nursing.

2/....The

The research was conducted at the University of Guelph and was partially funded by Ontario's Ministry of Agriculture and Food.

Farmatic Inc. of London, Ontario became involved in the project as a result of their expertise in the application of new technology. Had conventional systems been used, the Robotic Sow would have been cumbersome and unreliable. Through the application of new technology, Farmatic was able to dramatically reduce the number of moving parts, thereby reducing the number of potential problems.

A particularly difficult aspect of the development was overcome as a result of research done in the NASA Space Program. To maximise its quality, the formula fed to the baby pigs must be refrigerated. Hog barns are a very harsh and corrosive environment for equipment, and conventional refrigeration utilizes components with moving parts that could fail under those conditions.

The Robotic Sow's electronic refrigeration system uses the Peltier Cell developed by NASA for satellite cooling. These compact heat pumps are about the size of a book of matches and have no moving parts.

Animal welfare is an important issue these days, and the Robotic Sow addresses the issue by nurturing those animals that would have otherwise died. One fascinating aspect of this research is that the laboratory and field tests have demonstrated conclusively, that the Robotic Sow satisfies the piglets physical and psychological needs.

The Robotic Sow is magical! Everyone who sees it, is instantly captivated by the blue plastic mother that calls to her piglets by means of digitized grunts. This device is the result of scientific innovation and would have not been feasible, had it not been for the work of NASA and other researchers.

....
Cullum R.A. Johnston.

Mr. **Nelson**. All right.

Presenting a Portable Gas Leak Detector, Mr. Robert Turner.

STATEMENT OF ROBERT TURNER, PRESIDENT, MICROSENSOR TECHNOLOGY, INC., FREMONT, CALIFORNIA, PRESENTING A PORTABLE GAS LEAK DETECTOR

Mr. **Turner**. Yes, I'm Bob Turner from Microsensor Technology, and I'm going to briefly describe some technology that was developed for the Viking program.

NASA, when they were going to Mars, needed to monitor the atmosphere on Mars. And usually these gas analyzers are very large devices, they're roughly 100 pounds and they contain a lot of valves and sensors and tubing and so on.

And NASA had the concept that you could reduce mechanical components in silicon, much the way that integrated circuits have been done. So they went to Stanford University to their Integrated Circuits Laboratory and asked them if it would be feasible to reduce what's called a gas chromatograph—and that's for analyzing gases—if they could reduce that onto a silicon wafer.

The team there undertook this project and unfortunately it didn't get far enough along for the Mars mission, but since that time the EPA further funded it and then we broke away and formed the company and developed a commercialized what's called a gas leak detector or gas analyzer.

And we've reduced what is typically if you take like a two-drawer file cabinet, down to this component—(displaying)—and this is a complete gas analyzer here without the electronics. But all the mechanical components are in here.

And the heart of this technology, is this little silicon wafer—(displaying). This is a one-inch wafer. This contains two mechanical valves. It has about a meter of tubing in there, if you will, and flow restrictors and so on. So all your mechanical components are in this silicon wafer here.

Mr. **Nelson**. And that was originally being developed for Viking—

Mr. **Turner**. For the Viking program—

Mr. **Nelson**.—and the device was going to do what on Viking?

Mr. **Turner**. It was going to sample the atmosphere of Mars, on the Mars landing project.

Mr. **Nelson**. Thank you, Mr. Turner. That's fascinating.

[Information referred to follows:]

MTI microsensor technology inc.

NASA FY90 Auth
101-SSA
HEARING 4/13/89
DOCUMENT NO. 69

Date: February, 1989
Contact: Robert Turner, MTI
(415) 490-0900

MTI: Advancing Gas Analysis with a Portable Gas Chromatograph

The Technology

Gas chromatography (GC), the process by which compounds in an unknown mixture can be separated, identified and measured, is an important technique for analyzing gases in applications such as chemical and petrochemical processes, environmental monitoring, industrial hygiene, and forensics. Up until now, gas chromatographs were designed as laboratory instruments and, as such, their size made field use impractical.

The innovative application of silicon micromachining to gas chromatography has changed all this. By miniaturizing the GC, it becomes feasible to take the GC to the sample rather than limiting the analysis to the laboratory. Additionally, significant improvements in speed of analysis and system cost have been realized.

Silicon Micromachining started back in the 1970's at Stanford University when NASA asked them to develop a miniaturized atmosphere analyzer for their Viking Mars Lander. Silicon Micromachining is a technique in which mechanical structures are etched in silicon. MTI has etched all of the mechanical components of a gas chromatograph (GC) onto a single silicon wafer. The resulting GC system is approximately one twentieth the size of a conventional GC. This miniaturization not only provides portability but provides higher efficiency and much faster analysis times.

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41762 Christy Street • Fremont, CA 94538 • (415) 490-0900 • FAX (415) 651-2498

The Products

The M200D is a portable micro GC system with two independent GCs able to sample and analyze a wide range of gaseous mixtures. The front panel design makes it easy to set up for the operator. The M200D weighs only 12 pounds. Silicon micromachining has enhanced the thermal conductivity detector -- it has an exceptionally wide dynamic range of 1 ppm to 100%.

The M200S is a single-module micro GC system which, like the M200D, has all the capabilities of a full-size GC. It offers an upgrade path in the future for those customers who might need a second GC in the same housing.

The M200 gas chromatograph system's transportability is the key to allowing the customer to take "the laboratory to the field." MTI's expertise in gas analysis has brought speed, resolution, portability and modularity into one system.

The Markets

Our markets include . . . monitoring toxic fumes in the workplace . . . environmental monitoring . . . anesthesia monitoring . . . medical diagnostics . . . controlling process streams . . . and measuring the energy content of natural gas.

The versatility of the technology allows for a variety of customer applications. In the environmental area, a customer who is actively involved with the EPA and the NOAA is developing applications for the M200D for use at hazardous-waste and toxic-spill sites. They have developed a preconcentrator that allows 300 times higher sensitivity. Because of the speed of analysis, real-time analysis and multiple injections are completed in minutes. Environmental samples can cover a broad range of compounds, and the M200D's high specificity offers outstanding separation of these compounds while utilizing correlation chromatography for positive determination of unknowns.

Mr. NELSON. Now we have presenting the Fire Fighters' Ensemble, Mr. Duffy.

STATEMENT OF JOSEPH VITA, OCCUPATIONAL HEALTH AND SAFETY DEPARTMENT, INTERNATIONAL ASSOCIATION OF FIRE FIGHTERS, WASHINGTON, D.C., PRESENTING A FIRE FIGHTER'S ENSEMBLE

Mr. VITA. Thank you, Mr. Chairman. Very briefly I will just try to describe a program that we were involved with. My name is Joe Vita, I'm replacing Rich Duffy and I work in the Health and Safety Department with the International Association of Fire Fighters.

Following the death of three astronauts in 1968 in, I believe it was, Cape Canaveral, NASA began research and development to try to develop better materials, fire retardant materials and heat resistant materials and equipment to deal with fire and heat situations.

In 1971, our organization requested that NASA initiate a technology transfer program to try to take some of the research that they had done and material development that they had done and see if it could be applied to the fire service.

We were able to actually get some funding through NASA and we had several areas of concern that we wanted to address: the current clothing that people were using or the clothing that people were using at the time provided inadequate protection for the severe environments that they were occasionally exposed to, the weight of the clothing was a problem and heat stress was also a problem with the clothing.

So once we received funding with NASA, we worked with NASA and with advisory committees that were comprised of representatives of the fire service and we actually were able to complete several major tasks as part of this overall project.

One of the first and most important was the measurement of the actual structural fire fighters' work environment. This had never been done before. We were able to do industrial hygiene measures and find out what type of heat was actually confronting fire fighters in a fire environment. We were able to actually define various classes of fires.

Next, we were able to develop laboratory tests that could actually simulate the various classes of fires so that we could actually test materials, clothing and equipment in the laboratory to simulate conditions encountered in the field.

We actually saw the introduction of new materials to the fire service through this program. One that was developed for NASA was called polybenzymidozol, which most people refer to as PBI. This material has the best heat and flame resistance of any material available currently and it's actually utilized by a lot of our fire fighters throughout the country at the present time.

The next step after the introduction of materials was the development of actual clothing and equipment that was improved clothing and equipment, field testing of that equipment and also we were able to get funding for physiological testing to measure the effects of wearing clothing and equipment.

Our final results: this program—once the funding dried up for the program, our International Association of Fire Fighters actually carried on with the program, and the final results of the program:

Basically we are working with protective coat and trousers, helmets, boots for fire fighters. We were actually able to—we have specifications now for fire fighters' protective coats that utilize the PBI-Kevlar material for an outer shell, we use the Gore-Tex breathable moisture barrier for a moisture barrier and a lightweight liner.

As a result of our work with NASA, we were able to reduce the weight of clothing, we were able to reduce problems with heat stress and we were also able to increase protection from extreme heat and flame conditions that are frequently encountered.

In the area of fire fighters' helmets, we are using helmets now that are made of high temperature fiberglass. As a result of our environmental testing that we conducted, we found that the polycarbonate helmets that were used at the time, when exposed to regular fire environments, would actually melt or become very soft—they were not providing adequate protection.

And we also were able to introduce improved fire fighters' boots; we cut the weight down on fire fighters' boots—approximately cut it in half.

In conclusion, basically Project Fires led to the development of clothing and equipment for fire fighters that, one, provided increased protection in the environment in which they work and, two, we were able to provide clothing and equipment that was of reduced weight.

And one major problem that Chief Manahan referred to in New York is the weight of protective clothing and equipment in the past was a major factor in reducing fire fighters' work capacity at the scene of fires. And with the work with NASA and this project, we were able to reduce the weight of clothing significantly.

Mr. **Nelson**. Thank you, Mr. Vita. We appreciate that.

Now presenting Ovation Guitars, Mr. Kaman.

STATEMENT OF C. WILLIAM KAMAN, PRESIDENT KAMAN MUSIC CORPORATION, BLOOMFIELD, CONNECTICUT, PRESENTING OVATION GUITARS

Mr. **Kaman**. Thank you very much. I'm glad to be here. I'm sure everyone is wondering what guitars have to do with NASA, how does this relate to space? Really, it's in three areas: in our production methods that we produce the guitars by, in our materials that we use to produce them and in the design analysis that we used to create the guitars.

Ovation Instruments is a portion of Kaman Music Corporation, which is a small subsidiary of overall Kaman Corporation, which principal line of business is in the aerospace department. They started in 1945 making helicopters for the Navy, have gone on since then; we continue to do this. We also have done other contract work for other aerospace companies. We have also had some parts made that were on the space shuttle. So we've covered quite a bit in aerospace. And from a lot of that work is where the spin-off technology has come to the guitars.

We decided to get into a consumer business in 1966. The Company moved from being defense related—it was also in the industrial side, distributing bearings—we moved to the consumer side with our music business.

Ovation Guitars was what started it in 1966. And we are primarily known for our molded back of the guitar: instead of wood, we use fiberglass, which you can see on the guitars here. And I would invite you to come by later and take a good close look at them and play them.

Our backs are molded out of fiberglass material that was used in our aerospace division, originally as a wrap for the spruce rotor blades. It is now a molding compound that is really very similar to a type of compound that Corvettes are made out of.

The tops of the Adamas Guitars, which are the two you see in back here, the brown one and the red one, the tops of those guitars are made out of carbon graphite material as opposed to spruce, as the traditional guitars are. Carbon graphite, the material we use here, is also something that came out of the space field.

When we designed the guitars, the structure of the bowl and the shape, we used a lot of our aerospace lab equipment for the vibrational analysis. In doing that we determined the proper shape for that body to be that would be most comfortable for the player to hold, also the one that would project the sound the best. Because, really, with guitars, sound it what it's all about.

We also used the same testing equipment to come up with the various bracing patterns that are the structure for the inside of the tops, that not only hold the guitar up and keep it from collapsing on itself, but also provide the way the top vibrates, that produces the sound. From those areas, we were able to come up these guitars.

Since we introduced Ovation in 1966, we've probably built about half a million guitars, they are sold world- wide. They are produced primarily in this country, although we do have a lower entry-level line produced overseas for us.

And where we have gone since our initial introduction with the Ovation Guitar in 1966, it has grown to what is now part of Kaman Music Corporation. We also have a company that produces strings for guitars. We also have another company that produces solid body electric guitars, that a lot of the rock and roll players use.

We have also acquired wholesale music distribution companies that distribute instruments throughout the United States and we also have a branch—a company that sells our products as well as other products, musical products, throughout the rest of the world. And this has grown to where we now employ about 450 people and will have sales of slightly under $100 million this year.

So it's come from one idea of let's make a better guitar using space age materials to where we are a major force in the field of guitars, as well as a major force in the music industry.

Mr. Nelson. You may have explained this and I may have missed it, but how did you hook up with NASA in terms of the technology transfer over to you?

Mr. **Kaman**. The technology transfer primarily came from the use of composite materials and the use of production methods. Our parent company, Kaman Corporation, is involved in aerospace work, and from there we got the technology for the materials and the production methods.

Mr. **Nelson**. Well I want to thank you.

Mr. **Kaman**. Thank you.

[Information referred to follows:]

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KAMAN

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TECHNOLOGY AND GUITARS

Ovation Guitars were created in 1966 by an aerospace company that was seeking to expand via diversification into other market place segments. The parent company, Kaman Corporation, having been involved in the aerospace business from 1945 chose the consumer market for this expansion. The company had developed considerable expertise in working with wood and composites in the manufacture of helicopter rotor blades. Also, much of the vibration dampening work done for helicopter construction applies to guitar construction, in reverse!

The sitka spruce used for the tops in Ovation Guitars is the same as the spruce used in building rotor blades, since replaced by aluminum and other new composites. The fiberglass cloth used in making the original bowl shaped bodies was the same used to wrap the spruce rotor blades for additional strength and protection from the elements.

The sound of the guitar is the true test of performance. Spectrum analyzers and sweep generators from the aerospace development labs were used to develop the bracing construction of the guitars. The placement of the braces determines the sound characteristics as well as the strength of the guitar.

It was also from this development work that the unique bowl shape was developed. The semi-parabolic shape reflects and actually projects the sound from the inside of the guitar. This shape can be molded in a single operation using fiberglass material. Traditional guitars require several man hours to construct the wooden back and sides. Wooden guitars also absorb some of the sound energy reducing the overall output level whereas fiberglass absorbs very little.

In 1976 development work on a new soundboard was completed and the Adamas guitar was introduced. The Adamas features a soundboard constructed of two layers of carbon graphite fibers with a core of birch wood. Again using aerospace technology this combination of materials was selected and developed. The results are a guitar with superior sound that is ± 3 db over the entire playing range. Spruce top guitars are at best ± 12 db over the playing range.

Since the Adamas guitar was introduced in 1976, approximately 4900 have been produced. Since 1966, about 500,000 Ovations have been produced in total. In 1982, entry level models, which are made to our specifications overseas, were introduced. Both the U.S. and foreign produced Ovations are sold all over the world. The Ovation has grown to be recognized as an industry standard by which all others are judged. Ovations can be seen on stages with performing musicians around the world.

The tooling used in producing Ovations also has its origins in the aeropsace industry. Steel and aluminum fixtures with pneumatic and hydraulic clamping mechanisms can be seen throughout the factory. These assure high quality components and repeatability that traditional wooden fixtures cannot. Although the guitars are essentially hand-made, the high level of tooling allows the production manhours to be focused on the areas of greatest benefit, primarily the ornamental detail and playability.

The engineering team at Ovation continues to work on new ideas explaining the potentials of new materials applied to musical instruments. Their efforts are governed by the following premise:

In 22 years, Ovation Guitars has achieved a position of leadership in the world market of acoustic guitars through innovation and technical preeminence, and will continue to expend the necessary effort to maintain this position.

CWKaman II

4/11/89
C. William Kaman, II
President

Mr. **Nelson**. Now presenting a Simulation of the Virtual Environment Work Station, James Larimer, Chief of the Human Interface Research Branch, NASA Ames Research Center.

STATEMENT OF JAMES LARIMER, CHIEF, HUMAN INTERFACE RESEARCH BRANCH, AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA, PRESENTING A SIMULATION OF THE VIRTUAL ENVIRONMENT WORK STATION

Mr. **Larimer**. Mr. Chairman, members of the Committee, thank you. My name is Jim Larimer. I'm a vision researcher, a former Program Director at the National Science Foundation, and Chief of the Human Interface Research Branch at NASA's Ames Research Center. I manage a group of approximately 25 researchers, scientists and engineers working on problems related to vision, hearing, cognition and perception. An important element of our work is the application of this knowledge of human sensory and cognitive capacities to the design of control-interfaces for complex systems such as spacecraft and aircraft.

Our program is vertically integrated spanning basic to applied research We are working to develop mathematical models of the human visual system, to understand how the auditory system both externalizes and localizes sound sources, to understand how attention is controlled, and to understand how human beings perceive spatial relationships among objects in their environment.

Our base research and technology development supports applied research and applications in a broad spectrum of areas that include image communications and compression, 3D sound, remote control of robots, and the windowless cockpit.

The Virtual Workstation Project is one of the culminations of this research effort. It is an idea proposed and attempted in the 1960's by the computer scientist and leader in the field of computer graphics, Ivan Sutherland.

It is an idea that has been described and popularized in the science fiction literature called Cyberpunk. In this literature, a human, wearing a special device, something like this—(displaying product)—can virtually experience a remote environment, or one completely fabricated by a machine. The machine creates an illusion so compelling and so complete that it is like being there yet not being there. Being there and yet not being there means that you can give yourself extraordinary powers to fly through space, to see and walk through walls, or to scale your size to accommodate the space to be explored.

Our system, though far less compelling in its realism, nonetheless has many of these science fiction features. It is the first attempt, we believe, to create a virtual environment at an affordable cost. This technology, which is improving in quality and affordability daily, will change, perhaps revolutionalize, the way in which humans interact with computers, visualize information, and control machines.

Our goals in developing this technology were to aid planetary exploration, making it possible for a human to visually experience a remote and hostile planetary terrain without being there, to reconstruct and visualize the circumstances that have led to aviation accidents, to design and evaluate interfaces to control remote robots.

Other aerospace applications include the visualization of scientific data, avionic displays for the windowless cockpit, and a workstation for the evolutionary space station, one in which virtual controls can be rapidly reconfigured but, as computer generated images, have no weight and occupy no space.

The Virtual Workstation has many potential spin-offs of commercial significance. It will clearly be the computer interface of the future. Architects will use it as a computer aided design tool to design buildings and to experience them before they are actually built. It can be used in medical imaging and diagnosis. A pathologist will be able to explore tomographic 3D image in a manner similar to that depicted in the movie Fantastic Voyage.

Currently we are collaborating with a group in the surgery department at Stanford University to use the Virtual Workstation as a surgical planning tool.

It can also be used in instruction to visualize anatomy. For example, by shrinking one's virtual self, you could walk through the convolutions of the brain or the chambers of the heart. It can be used as a training device, part of a flight simulator, for example. Moreover, in the near future, you can expect to see a low resolution version of it appearing as a new kind of arcade game.

Finally, work is already proceeding to use the Virtual Workstation as a tool for understanding low vision, a pathology of the visual system that disables thousands of aging Americans each year. Moreover, it has the potential to be use as a visual prosthesis to enhance the failing vision of this large disabled group of citizens.

And later on I can show you pieces of it.

[The prepared statement of Mr. Larimer follows:]

104

#12

NASA
National Aeronautical and
Space Administration

Hold for Release Until
Presented by Witness

April 13, 1989

Subcommittee on Space Science and Applications

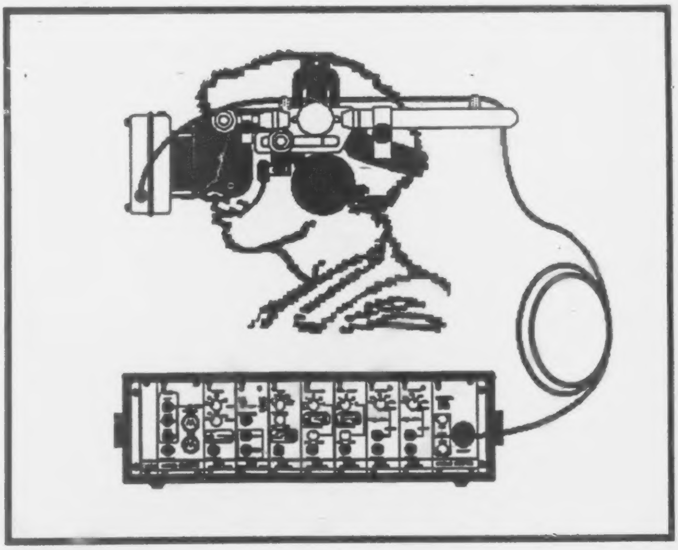
Committee on Science, Space, and Technology

United States House of Representatives

Statement by:

JAMES LARIMER

Chief
Human Interface
Research Branch
Ames Research Center



101st Congress

STATEMENT
OF
Dr. James Larimer
Chief
Human Interface Research Branch
NASA Ames Research Center
before the
Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology
United States House of Representatives

Spoken Remarks

Mr. Chairman and members of the committee, thank you for inviting me to make this presentation. My name is Jim Larimer. I am a vision researcher, a former Program Director at the National Science Foundation, and Chief of the Human Interface Research Branch at NASA's Ames Research Center. I manage a group of approximately twenty five scientists and engineers working on problems related to vision, hearing, cognition, and perception. An important element of our work is the application of this knowledge of human sensory and cognitive capacities to the design of control-interfaces for complex systems such as aircraft and spacecraft.

Our program is vertically integrated spanning basic to applied research. We are working: (1) to develop mathematical models of the human visual system, (2) to understand how the auditory system both externalizes and localizes sound sources, (3) to understand how attention is controlled, and (4) to understand how human beings perceive spatial relationships among objects in their environment.

Our base research and technology development supports applied research and applications in a broad spectrum of areas that include image communications and compression, 3D sound, remote control of robots, and the windowless cockpit. The Virtual Workstation Project is one of the culminations of this research effort. It is an idea proposed and attempted in the 1960's by the computer scientist and leader in the field of computer graphics, Ivan Sutherland. The virtual workstation is described and popularized in the science fiction literature called Cyberpunk. In this literature, a human, wearing a special device, can virtually experience a remote environment or one completely fabricated by a machine. The system creates an illusion so compelling and complete that it is like being there yet not being there. Being there and yet not being there means that you can give yourself extraordinary powers to fly through space, see and walk through walls, and to scale your size to accommodate the space to be explored. Our system, though far less compelling in its realism, none-the-less has many of these science fiction features. It is the first attempt, we believe, to create a virtual environment at an affordable cost. This technology which is improving in quality and affordability daily, will change, perhaps revolutionize, the way in which humans interact with computers, visualize information, and control machines.

Our goals in developing this technology were: (1) to aid planetary exploration, making it possible for a human to visually experience a remote and hostile planetary terrain without being there, (2) to reconstruct and visualize the circumstances that have led to aviation accidents and incidents, and (3) to design and evaluate interfaces to control remote robots. Other aerospace applications include: (1) the visualization of scientific data, (2) avionic displays for the windowless cockpit, and (3) a workstation for the evolutionary space station, one in which virtual controls can be rapidly reconfigured, but, as computer generated images, have no weight and occupy no space.

The Virtual Workstation has many potential spinoffs of commercial significance. It will clearly be the computer interface of the future. Architects will use it as a computer aided design tool to design buildings and to experience them before they are actually built. It can be used in medical imaging and diagnosis. A pathologist will be able to explore tomographic 3D images in a manner similar to that depicted in the movie Fantastic Voyage. Currently we are collaborating with a group in the surgery department at Stanford University to use the virtual workstation as a surgical planning tool. It can also be used in instruction to visualize anatomy; for example, by simply shrinking one's virtual self, you could walk through the convolutions of the brain or the chambers of the heart. It can be used as a training device, part of a flight simulator for example. Moreover, in the near future you can expect to see a low resolution version of it appearing as a new kind of arcade game. Finally, work is already proceeding to use the virtual workstation as a tool for understanding low vision, a pathology of the visual system that disables thousands of aging Americans each year. Moreover, it has potential as a visual prosthesis to enhance the failing vision of this large disabled group of citizens.

Thank you.

STATEMENT
OF
Dr. James Larimer
Chief
Human Interface Research Branch
NASA Ames Research Center
before the
Subcommittee on Space Science and Applications
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NASA's Virtual Workstation is a personal simulator and telepresence device. It is an advanced human-interface device for interacting with computers, and it also provides highly dextrous remote control of telerobots. In both of these applications, the Virtual Workstation surrounds the human user with a virtual environment. That is, either the computer creates an artificial reality built up from digital models, or a remote robot can transmit and receive sensory information so that the user has a feeling of presence at the robot's worksite.

The system consists of a very wide field-of-view, stereo head-mounted display, instrumented gloves for tracking hand shape, head and hand position and orientation sensors, three-dimensional sound generators, and a voice interaction system. When using this system, the visual, auditory, and tactile environment of the user is replaced by a remote or artificial task environment.

Researchers (primarily Dr. Michael McGreevy and Mr. Scott Fisher) at NASA's Ames Research Center developed this system as part of a long term research program in spatial information transfer between humans and automated systems in aerospace applications. Because of the compactness, relatively low cost, and potentially revolutionary applications of the system, NASA's personal simulator and telepresence device has generated considerable interest in industry, academia, the military, and in the popular media worldwide.

NASA is currently applying this technology in a number of areas, including: core human factors research under the R&T base program; advanced operator interfaces to telerobots under the Automation and Robotics Program; evolutionary Space Station crew systems under the Space Station Advanced Development Program; and terrain visualization systems to support planetary exploration, under the Pathfinder Program.

The Virtual Workstation shows particular promise for virtual planetary exploration. The planets and their moons offer vast spatial environments for exploration. The pictures which sample these environments should not be considered only as end products to be displayed on graphics terminal screens or as photographic prints. Instead, planetary terrain can be recreated from the pictorial data and explored using environmental displays such as the Virtual Workstation.

Future applications include simulation and evaluation of crewstations, cockpits, and spacecraft module interiors. For example, in cooperation with the Army, a complete rotorcraft cockpit will be simulated, including operating instruments, realistic out-the-window scenes, and a virtual crewmember. Visualization of air traffic will also benefit from the Virtual Workstation.

Work is progressing to use the virtual workstation as a data display and management system for tasks such as displaying computer simulated fluid flows. The system can be used to create a display environment in which data manipulation and system monitoring tasks are organized in virtual display space around the operator. In addition, the ability to network Virtual Workstations will soon provide shared workspace environments for collaborative systems management and Telescience applications from remote locations.

NASA has been approached by a variety of companies, universities, military research labs, and entrepreneurs who are interested in diverse spinoff applications of the Virtual Workstation. NASA Ames is currently establishing Memoranda of Understanding, and other mechanisms, to assist technology transfer. Spinoff applications include advanced visualization systems for: computer-aided design, architecture, medical imaging, medical training, entertainment, low-cost part-task flight simulators, and computational fluid dynamics, to name a few. NASA is currently working with the State of California and two California-based companies, for example, to develop demonstration systems for Virtual Computer Aided Design.

We have sent complete schematics of the system hardware to dozens of inquiring organizations, and we are preparing to make the software available as well. More importantly, we are very active in communicating with interested parties, and in encouraging interested organizations to visit our laboratory for demonstrations.

NASA's Virtual Workstation, a personal simulator and telepresence device, has touched a nerve. We believe that a huge potential market could derive from further developments of this technology. It is worth mentioning that the parallel development of High Definition Television (HDTV) and advanced flat panel displays will accelerate Virtual Workstation technology development and its dissemination. We are especially interested in commercialization as a mechanism to spur this development.

References

Foley, J. D. Interfaces for Advanced Computing, **Scientific American**, October, 1987.

Fisher, S. S., McGreevy, M., Humphries, J. and Robinett, W. Virtual Environment Display System. In **Proceedings 1986 Workshop on Interactive 3D Graphics**, ACM SIGGRAPH.

NASA Tech Briefs, July/August 1988.

Mr. Nagle (Presiding): We thank you. We thank you.

The next presentation is the Electro-Expulsive Separation System by Leonard Haslim, Project Manager, NASA Ames Research Center.

STATEMENT OF LEONARD HASLIM, PROJECT MANAGER, NASA AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA, PRESENTING THE ELECTRO-EXPULSIVE DEICING SYSTEM

Mr. **Haslim**. Thank you, Mr. Chairman, and members of the Committee. I thank you also for your support of NASA that has been on-going and deeply appreciated.

I have a formal written presentation that I will submit for the record and, by your leave, I would prefer to just wing it, if you'll pardon the pun.

Mr. **Nagle**. Permission granted.

[Laughter.]

Mr. **Haslim**. Thank you, sir.

I've got to get used to that—I'm a Naval Reserve officer and I've got to say Aye, Aye, Admiral Truly.

[Laughter.]

Mr. **Haslim**. Just briefly referring to some of my notes:

This technology was originally developed for aircraft deicing. And the motivation was: according to the National Transportation Safety Board, ice caused 344 aircraft mishaps in the decade following 1977, 124 fatalities in which—fatal accidents, rather, in which 443 people perished.

Like you, I am keenly and deeply grieved at what I consider needless fatalities and, as a former and long time Naval Aviator, I am quite sensitive to the effects of icing on the operational capability of aircraft and the loss of lives.

About 1980, I started for NASA Ames a research project to evaluate an upgraded version of a pneumatic deicing boot system for rotor blades. And whereas the system did have promise, I saw a lot of shortcomings and I thought there ought to be a better idea. And, after paining my brain, finally something clicked, and a consequence of this was what I will now demonstrate, the Electro-Expulsive Deicing System.

Although I realize that you will not be able to see it as well from a distance, later on you can come up and see this.

The system really consists of a very durable polyurethane film, like my fly snapper here, a space age device—(demonstrating)—which has very high resistance to sand and rain erosion. This is a characteristic feature needed for deicing the leading edge of aircraft surfaces.

This elastomeric material would have embedded in it pairs of conducting strips of copper, shown here in this exaggerated thickness—(indicating). The strip goes in beyond and comes back out in a folded manner. And they're done in pairs and they straddle slits that are deliberately placed in the elastomeric material.

When a bank of capacitors charged cause a current surge to pass through one part of the conducting ribbon, around and back—it's going in opposite directions—and, learing from previous work where I was accelerating protons to 40 KEV simultaneous with UV exposure and vacuum for an in situ exposure similitude for thermal controlled surfaces, I observed that the conductors were distended horribly, where they were actually ripping the nylon straps. So putting that in the noggin for future reference, I then recalled it for this application.

And what we have is an electromagnetic repulsive force between the conductive strips that causes a distention of this elastomeric film very vigorously to go from this configuration to this one—(indicating)—and back again in about 200 microseconds, exerting a normal force to the surface of anywhere from 700 to 2500 g's.

Any ice that has accreted on this surface—which is bonded onto the leading edge of the airfoil, say—causes the ice to be shattered, pulverized and kicked clear across the street. And in a little while, I'll demonstrate it here. Again, by your leave, I caution you that this is a bit noisy, it sounds like a pistol going off, but it's quite harmless—otherwise, I wouldn't be standing here.

[Laughter.]

Mr. HASLIM. Well let's see...

Some of the other applications, not only is this applicable to aircraft deicing and has the potential of savings lives, but it's also applicable to nautical applications and terrestrial applications.

For nautical applications, the Navy is keenly interested. I'm told that in one scenario in the North Atlantic a Navy cruiser can accrete as much as 1.5 million pounds of ice, and improperly distributed you can imagine what they would do to its roll characteristics.

My cohorts and I at NASA Ames just returned from the Bering Sea at the invitation of the State of Alaska, where we demonstrated our system as both an anti-ice and a deicer for the fishing fleet, where they have lost a considerable number of fisherman: in this last season we're told 12 ships went down with as many as 80 fishermen perishing.

For other than nautical applications, we have such applications as communication towers, transmission towers...

We have just been told the successful results of one of the licensee's work on Mount Washington, where two months of continuous operation demonstrated the ability of the system to keep the structure free of ice where it was applied.

And this one company—an American company, Mr. Schiff, where are you—is quite successful and, under the license granted by NASA, is attempting to commercialize this, both for rotorcraft and large transports.

Why would one want to use a system like this? Well consider it's lightweight, it's easily bonded onto any applicable surface, the leading edge of the wing, the tailfeathers, the engine inlet or whatever, low cost, lightweight, easy applicability, retrofitability and, more important than anything else I believe, it works and it works at a very low power consumption: perhaps 500 to 1000 watts is all that's needed to deice a full size aircraft; that's essentially a landing light.

Now if you'll bear with me, I'll have a cohort demonstrate—and if you'll hang onto your ears—what I have here, because we don't have the facility to coat this with ice, are rectangles of thin blue plastic. Using your imagination, you will see that this ice, this plastic ice, will go blowing up in the air and Whoosh, she's gone.

[Demonstrating product.]

[Applause.]

Mr. Haslim. And that is with a toned-down power supply.

By the way, before you leave, Mr. Packard, this is a San Diego guy that's talking to you.

Mr. Nelson (Presiding): Thank you, very much.

[The prepared statement of Mr. Haslim follows:]

109

#13

National Aeronautical and
Space Administration

Hold for Release Until
Presented by Witness

April 13, 1989

Subcommittee on Space Science and Applications

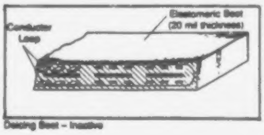
Committee on Science, Space, and Technology

United States House of Representatives

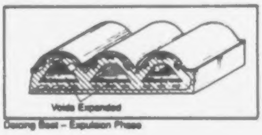
Statement by:

LEONARD HASLIM

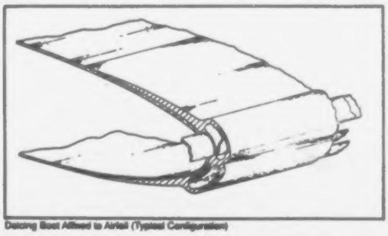
Project Manager
Civil Technology
Office
Ames Research Center


Conductor Loop
Elastomeric Boot (20 mil thickness)

Deicing Boot – Inactive


Voids Expanded

Deicing Boot – Expulsion Phase



Deicing Boot Affixed to Airfoil (Typical Configuration)

101st Congress

Written Testimony
by
Len Haslim
NASA Ames Research Center

Presented to the Subcommittee on Space, Science and Applications,
Committee on Science, Space and Technology,
U.S. House of Representatives

Gentlemen, I am deeply honored to be here today and would like to personally thank you for all the support that you give to NASA. I will demonstrate an Electro-Expulsive Separation System (EESS) to you that has tremendous promise as a deicer and as an anti-icing protection system for aeronautical, nautical, and terrestrial applications.

I have always been very concerned about safety and deeply saddened when tragedies occur. When I was a Navy pilot, I became very sensitive to icing of aircraft because of the operational restrictions and the loss of lives due to icing. In 1980 I began a research project at NASA Ames to develop and flight test an improved pneumatic deicing system for a helicopter rotor. Although the concept had promise, I felt it had limitations that preclude its effective use. One day an idea for a completely new method to deice clicked in my mind, and that resulted in the EESS concept.

The system consists of a flexible, highly durable polyurethane sheet covering a wing surface with parallel pairs of conductive copper ribbons sandwiched in-between. Pulses of direct current, which have been stored in a capacitor bank, surge through the conductor pairs creating opposing electromagnetic fields which induce the ribbons to repel one another. This action then causes the polyurethane sheet to distend a small fraction of an inch, pulverizing and ejecting any accreted ice. The system causes virtually no aerodynamic penalty since it is only twenty thousandths of an inch thick and operates in bursts lasting only two hundred microseconds. The main advantages of the EESS are that it consumes as much as 500 times less power than currently used electrothermal systems, is very compact and lightweight, and it is simple to install, in most cases. It is even retrofittable on current aircraft. The NASA system has been proven effective in numerous icing tests conducted in government and industry wind tunnels; and a joint NASA, Navy and industry effort recently resulted in several successful flight tests on NASA Lewis' Twin Otter and the Navy's F/A-18 Hornet in actual icing conditions. As a consequence of these successes, user interest has snowballed. NASA has granted commercial licenses to a private sector company who is now seeking to outfit both commercial and military aircraft with the EESS.

The EESS has great potential for many non-aircraft applications as well. Protection of ships is one such application. We recently conducted a successful EESS shipboard experiment in the Bering Sea with the State of Alaska to demonstrate deicing of fishing boat superstructures. I am told a Navy cruiser can accumulate over 1.5 million pounds of ice in severe weather. The Navy and a ship builder are planning a feasibility demonstration of the EESS on a cruiser for next winter. Another application is transmission tower deicing. This past winter a private sector firm has demonstrated successful continuous operation for two months under actual icing conditions on Mt. Washington, NH. Other possible spin-offs are bridge surface deicing and releasing parts from their molds during manufacture. A novel application of the EESS technology is a self-pumping fluid tube where pulses of electrical current designed with hydraulic systems could imitate peristaltic action. Thus, it may be possible for a microtube to be used for arterial replacement.

I am very proud to be provided the environment and the resources within NASA that give me the opportunity to fully develop my ideas.

Mr. **Nelson**. Presenting the UV Filtered Lenses, Mr. Mittelman.

STATEMENT OF ALAN MITTELMAN, PRESIDENT, SUN TIGER, INC. LA CRESCENTA, CALIFORNIA, PRESENTING UV FILTERED LENSES

Mr. **Mittelman**. My name is Alan Mittelman, and I am President of Sun Tiger Biomedical Optics in North Hollywood, California. We manufacture optical quality protective lenses and a special sunglass which is a direct NASA spin- off.

I'd like to introduce Ms. Laurie Johansen, who is a former NASA scientist, and Ms. Johansen, in concert with a former NASA JPL engineer, Mr. Paul Diffendaffer, co-invented the Sun Tiger lens.

Ms. Johansen.

Ms. **Johansen**. Thank you.

We developed a new class of sunglass which is of special use to people who either want to have extraordinary levels of protection or who want to see very well at the same time.

I left JPL in order to develop this design, but the spin-off application is basically that I learned from JPL some of the problem-solving and information-gathering skills there and also the very early versions of the sunglass were developed by people who were at JPL, although it was not actually funded by JPL to do that.

I'd like to demonstrate some glare. I brought my own portable glare source indoors here for you. And while Alan is giving out glasses to the representatives, I'd like to explain a little bit about why these glasses were designed the way they are and why they work.

People who would like to see afterwards can experience the glare for themselves with the glasses, after this is over.

If you look at the eye, you can see—this is the front portion and this is the rear, the back of the eye—(indicating). And ultraviolet is a high-energy, short wavelength—

Mr. **Nelson**. Would you mind turning that chart so we can see it?

Good.

Ms. **Johansen**. Okay. Ultraviolet is at the shorter end of the spectrum and, as a result, it has more energetic photons. And these photons are energetic enough that they can actually damage tissues and are easily absorbed.

In the front of the eye, the cornea, is where—the site of snow blindness that occurs when you're exposed to high levels of ultraviolets, such as off of snow-laden slopes and so on.

Ultraviolet is also implicated in cataracts. Over a lifetime, the lens darkens and becomes cloudy with exposure to ultraviolet. And so it's worthwhile to block the ultraviolet.

In addition, slightly longer wavelengths, which are in the visible, which are violet and ultraviolet—I mean, violet and blue light, they pass through the cornea and lens and actually impinge on the back of the eye where you see blue and violet with the cells in the retina, and they also damage those cells over a long period of time. They have been implicated in loss of night vision and also in macular degeneration. The two leading causes of blindness in the United States and in the Western world are cataracts, which are linked to ultraviolet exposure, and macular degeneration, which is linked to blue and violet exposure.

In addition, we found from our calculations that the glints of light which are reflected off of water surfaces such as pavement and snow can also cause damage, even with the longer, less damaging wavelengths merely because of their high intensity. And so, as a result, we also incorporated a polarizing filter which blocks the light which is bounced off of surface—horizontal surfaces.

And I'd like to demonstrate an example of glare and show you how the lenses work, for those people who have gotten the glasses.

This piece of glass is used to bounce the light so that the light is polarized coming off of it, and if you—for example, Mr. Rohrbacher there, can see the difference with and without.

[Demonstrating product.]

It would help a little if the lights could dim just a bit, so I can see my spot there.

You can see the difference...

[Demonstrating product.]

Okay. Can we have the lights back up, please?

As you can see, there's a great difference with them and without. This is a high blue source, much like sunlight, and the exposures you're getting over there is about what you'd be getting if you were at the beach on a sunny day in the middle of summer, as far as the glints are concerned off of this pane of glass.

Mr. NELSON. What is it that makes the distant objects clearer?

Ms. JOHANSEN. By blocking the blue light, it also reduces the effect of wave scattering. If you look out into the sky and you see that it's blue or, in the case of haze, it's a bright bluish haze, this is because the particles in the atmosphere refract the light around them to a larger degree when they're blue or violet wavelengths. By removing that, you cut out the visual effect of the haze.

And this has a special benefit for pilots who have been, up to this date, our principal customers: because they can see through the haze much better, spotting other aircraft and improving aviation safety that way.

Mr. ROHRBACHER. And, Mr. Chairman, I might add that I've known about this product for a few years, and when I worked at the White House I passed on a few of these glasses to some Mujtahid commandos in Afghanistan and they were able to spot some Soviet aircraft in time.

[Laughter.]

Ms. JOHANSEN. The glasses also have benefit to police and military personnel in that they protect night vision during the day, because they're so extraordinarily protective of the retina and they preserve the rodoptsin so that—for example, if you were wearing these glasses and you walk into a theater, you don't have the couple of minutes of adaptation time, you can walk in, take them off and see almost right away. And that also works for like SWAT teams and police and so on.

It also has special benefits to people who have impaired vision who—for example, in retinitis pigmentosa, they are recommended by the Retinitis Pigmentosa Foundation for their patients because their repair mechanisms in their eyes aren't up to par and, as a result, it helps to give them the extra protection against the sun.

Also older eyes, the repair mechanisms decline with age and, as a result, older persons, you know, who are beginning to lose some of their vision, it's prudent for them also to wear these glasses because it may help keep their repair mechanisms in pace with the damage that sunlight has been causing to them over their lifetime.

They're also good for regular people who just want extraordinary levels of protection and want to be able to see well at the same time. Most very protective glasses are very dark, such as welders' glasses and so on, you can't use them out in the open.

[Information referred to follows:]

For Immediate Release: 13 April 1989

101-SSA
NASA FY90 Auth
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76

SUNTIGER POLARIZED SELECTIVE TRANSMISSION SUNGLASSES

New NASA Spinoff Sunglass Lens Reduces Eye Damage

The Suntiger lens is unique in its ability to improve and protect vision. It was designed based on the latest information regarding damage mechanisms to the eye. It is the most effective sunglass that has been designed to date.

Suntiger lenses are designed to selectively block only the harmful aspects of light and allow the useful light to transmit. Accordingly, Suntigers protect eyes better and allow better vision. The two leading causes of blindness in the United States and other Western nations are cataracts and macular degeneration. These diseases have been linked to exposure to ultraviolet, blue and violet wavelengths of light. Suntiger lenses block these damaging wavelengths. Long term use of these lenses will reduce the risk of developing these age-related forms of blindness.

People who use the lenses include two groups. People who need to protect their vision very thoroughly wear these lenses for their protective properties. These people include post-cataract patients, persons with retinitis pigmentosa, and people who have age related vision reduction. People who need to see well in bright sunlight also use these lenses for their immediate vision enhancing abilities. Examples of these people are pilots, drivers, military personnel, and search and rescue personnel. The improved vision is so pronounced that many pilots use these glasses and credit them with improving aviation safety.

These sunglasses were not directly evolved from a particular NASA program. Instead, they evolved out of the scientific community interaction between NASA engineers and scientists that often occurs at NASA. NASA's Jet Propulsion Laboratory (JPL) brings people from many technical disciplines together to form a technological melting pot of technical information. It was in this creative environment that the originators of these lenses met each other and decided to design, produce, and market the lens on their own time.

The originators of the lens left JPL and started the Suntiger company. After further research and development, a patent was filed by Laurie Johansen and Paul Diffendaffer in the United States, Japan, Europe, S. Korea, Australia and Canada. These lenses are now being produced on a mass production basis.

For more information contact:
Alan Mittelman, President, Suntiger Biomedical Optics Inc., 7047 Radford, North Hollywood, California, 91605, (818) 765-2700, FAX: (818) 765-2952.

Mr. Nelson. Well we appreciate this very much.

Questions from the members?

[No response.]

Thank you, Mr. Mittelman. We appreciate that.

Presenting Metallized Products, Mr. McHugh.

STATEMENT OF PATRICK MC HUGH, METALLIZED PRODUCTS, INC., WINCHESTER, MASSACHUSETTS, PRESENTING METALLIZED PRODUCTS

Mr. McHugh. Metallized Products is a company that really, truly and honestly grew out of NASA. About 30 years ago NASA came to a little company in Massachusetts called the National Research Corporation, headquartered in Cambridge, came in with an idea about taking metallized materials we were doing strictly just for decorative purposes, it was gift wrap and things like that, it was a very, very small industry. And they had an idea for a little thing called Echo-1, a communications satellite program.

Echo-1 was nothing more than a large balloon, about ten stories high. This balloon had to be compacted down though into a basketball-sized container to be put into orbit and then inflated. And a few people this morning from NASA told me they can remember you used to be able to see it, visually, floating around up there.

What it was was the first time that they had bounced a signal out into space and brought it back in in a controlled environment. That was Echo-1. That required a precise amount of aluminum to be deposited on a very thin film. The film that was used was a polyester film that was one-quarter of a mil thick. The amount of aluminum that was put on it in a precise deposition was one-millionth of an inch thick. So this lightweight vehicle could be sent into outer space. That was 30 years ago.

In 1964, we took this same technology of applying aluminum in precise depositions and we found out that on earth it creates another unique environment, okay, that environment being the idea of it can reflect your body heat, and we developed the space blankets. The space blankets are 25 years old. They've saved countless of thousands of people's lives, both in the military, ski patrol, National Boy Scouts Association, they're used in medical operations and they're still being sold today.

And for Mr. Schiff, who has left, they are made in America.

Some of the other things that came out of this technology and the continuing technology that Metallized Products continues to do with NASA has been all the shiny gold material you see on the lunar lander and the space shuttles and so forth. That technology comes back to earth. Your potato chip bags today are metallized because of the technology that grew out of NASA's need for a product. Simple things like that.

A material that we developed in concert with NASA when they used to land the satellites back into the water was the life raft canopies and the floatation cower. That wasn't anything greatly unique except they were radar reflective and they were thermal protective for the astronauts because sometimes they landed 200 miles away from the ship and they needed some way to sight—visibly sight these people and also visibly to pick them up on radar.

Metal, in precise depositions, if it's moving in a lightweight environment, is radar-reflective.

The original material that was utilized, the 25 gauge material that was utilized in the Echo-1 satellite, today insulates all liquid hydrogen and liquid helium tanks in a pure vacuum. It's still used on the shuttle today. It's still used on every satellite. Every time you see something up there that's flintering and glittering around, that is a thermal barrier, a radiation thermal barrier in outer space.

The most important thing is that all these things that through this industry have come back and have become a company, not just my company, Metallized Products, but an industry that exists today. And it probably never would have got there unless there was the spin-off—you know, the need for the product to be spun-off.

There's one other spin-off that I really haven't heard an awful lot about here today I'd like to talk about and that's something that NASA gives us, and that's pride: pride in being an American, pride in being, you know, the people that can still put someone on the moon, put people up there and bring them back. My packaging says it's a NASA spin-off and I'm damned proud of it. And I hope we all get proud about NASA and keep supporting them.

Thank you.

Mr. NELSON. Well we appreciate that. Thank you.

[Applause.]

[Information referred to follows:]

MP METALLIZED PRODUCTS, INC

FACT SHEET

BUSINESS:

- Vacuum metallization through induction heated sources on roll materials.
- Electron Beam radiation curing for specialty lamination and coating of roll materials.
- Fabrication, Packaging and Marketing of Consumer focused Outdoor Safety Products.

HISTORY:

- Established in the post World War II era of new business developments, the primary market focus of **METALLIZED PRODUCTS, INC.** has been the pioneering of technological advances in the process of vacuum metallization and the engineering of specialty coatings and laminations on a wide variety of material substrates.

METALLIZED PRODUCTS, INC. has been a primary supplier of metallized film insulation materials for all unmanned and manned spacecraft from the early balloon launched communication satellites through to and including the Space Shuttle program. **METALLIZED PRODUCTS, INC.** has always been in the forefront of reflective insulation technology, meeting the critical standards of **NASA** and its many sub-contractors. Some of the unique materials developed in concert with **NASA** are readily visible in the photos of the "Shiny Gold" material that we all have seen on the Lunar Lander, the inside of the Space Shuttles Cargo Bay, the Canopy over the Skylab and the protective covering used on all satellites.
This special material affords the needed protection to the sensitive electronics in the outer space environment, by providing a thin, lightweight reflective insulation barrier.

The acquired technology from producing these specialty materials for **NASA**, has been extended to the design and development of direct by-product lines of materials that will be effective in Earth's atmosphere.

Metallized Products, Inc.
37 East Street
Winchester, Massachusetts 01890
(617) 729-8300 Telex: 951992
FAX (617) 729-9093

PRODUCTS: Technology from **NASA** inspired developments has led to the following "SPIN-OFF" products:

- **NRC-2® SUPERINSULATION**
  - Cryogenic Insulation Material
  - .00025" Thickness, Multi-layer use
- **TXG® LAMINATE**
  - Radar Reflective Life Raft Canopies
  - Salt, Corrosion Resistant Highly Visible
- **THE ORIGINAL SPACE® BLANKETS**
  - Reflects and Retains 80% of Radiated Body Heat
  - Lightweight, Compact Life Saving Products
- **HEAT-SHIELD™** BUILDING INSULATION
  - Reflective Inner Wall Lining
  - Prevents Heat Loss from Radiation
- **FIRE PROXIMITY SUIT** MATERIAL
  - Reflective Outer Layer Material
  - Specific Metal Density on Both Sides
- METALLIZED **KAPTON®**
  - Continuing Aerospace Applications
  - High Temperature Aviation Insulation

MARKETS: **NASA**, Sub-contractors for **NASA**, Building Trades, Computer Industry, Electronics Industry, Packaging Markets, Specialty Markets, Consumer Products, Fashion Industry, and a wide variety of Manufacturers worldwide.

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Consumer Products Group

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FAX: 617-729-9093

Mr. **Nelson**. Now presenting the Computational Fluid Dynamics/Artificial Heart Flow, Mr. Kutler.

STATEMENT OF PAUL KUTLER, CHIEF, FLUID DYNAMICS DIVISION, AMES RESEARCH CENTER, MOFFETT FIELD, CALIFORNIA, PRESENTING THE COMPUTATIONAL FLUID DYNAMICS/ARTIFICIAL HEART FLOW

Mr. **Kutler**. Mr. Chairman, members of the Subcommittee, I welcome this opportunity to appear before you and discuss an application of technology originally developed by NASA for the space program and sponsored by the Office of Commercial Programs, Technology Utilization Office. It is a typical example of a good working relationship between a main line research organization and the Office of Commercial Programs.

Within NASA, I lead the Fluid Dynamics Division at Ames Research Center. It's a division that uses computers to do flow simulations, as well as wind tunnels, to do analog simulations.

Within my division, there is an Applied Computational Fluids Branch that develops application software to solve aerospace-related flow problems. It's in that branch that this current project is taking place.

Let me put up this chart:

This project was designed by me to simulate the flow in an artificial heart device with technology originally developed for numerically simulating the flow in components of the space shuttle main engine. It was conceived as a result of an article I read in Time Magazine regarding the fluid flow problems associated with these artificial heart devices.

This chart depicts regions of the space shuttle main engine where we've developed technology to understand the flow physics in some components of that engine. The technology on the left is currently being used for our artificial heart project, while the technology on the right here—(indicating)—can be used to simulate flow in ventricular-assist devices such as the hemo pump, shown up here—(indicating).

This same applications software has also been disseminated to the automobile industry and it's used to simulate flows around automobiles, as well as flow inside the passenger compartment. It's also been used for hydrodynamic applications such as simulating the flow around components of subsurface ships.

I would now like to show you a video that depicts the program we've put together for simulating the flow in the artificial heart and show some of the numerical solutions we've obtained to date.

[Whereupon, a videotape was played.]

Mr. **Kutler**. To accomplish this technology utilization project, a collaborative program was established among Penn State University, the Hershey Medical Center, Stanford University and Stanford Medical Center, as well as NASA Ames Research Center.

The technology pioneered to date is being used by the developers of the Penn State heart to understand the flow and compare it with their experimental observations. Eventually this technology will be available to anyone for use in the design of advanced artificial heart systems.

The spin-off technology that's been developed is being applied to simulate the flow in the Penn State artificial heart. I have a part of one of those hearts here—(displaying).

The Penn State heart is an electromechanical device powered by inductance from an externally-carried battery, so it's not necessary to have any pneumatic tubes going through the body.

The flow inside the heart is very complex, it's difficult to predict and it's hard to observe experimentally. It's known that blood flowing through such prosthetic devices can be damaged by the fluid dynamic shear stresses. In addition, regions to separated flow caused by corners in the geometries of these breeding devices are breeding grounds for blood clots that can lead to strokes. The mechanical check valves or heart valves that are an integral part of this artificial heart are noisy, but yet a comforting indication to the patient that everything is working properly.

It's important that the designers of these devices have a good understanding of the flow behavior in order to suggest configuration changes to improve the flow quality. To accomplish this, they can either perform experiments or utilize a numerical simulation called computational fluid dynamics, such as you're seeing here.

Computational fluid dynamics, or CFD as it's known, involves a numerical solution on supercomputers of a complicated set of mathematical equations that describe the behavior of fluids. Solutions from CFD are information rich and they provide the designer with a complete description of the unsteady flow field of interest in contrast to what can be obtained experimentally. Changes in the geometry to enhance the flow quality are easily implemented, cost effective and thus attractive to the developers.

What you're seeing are the numerical simulation of flow paths being released in the inlet of the heart during in- flow and how their position changes as the heart beats.

Although the simulation of one heartbeat requires several hours of computer time on the world's fastest supercomputer, it provides other unobtainable information.

The supercomputer employed for this project is the Cray 2, located at NASA's Numerical Aerodynamic Simulation Facility in California. It's speed is equivalent to approximately 50,000 IBM personal computers.

Adaption of existing technology to the artificial heart resulted in two advancements that have spin-back applications for NASA for performance enhancements of the space shuttle main engine, as well as other aerospace applications.

The first advancement was the development of a time- accurate incompressible, the Navier-Stokes solver, and the second was the developing of a moving surface boundary condition procedure, both of which have been completed.

The current CFD technology that you've seen demonstrated today has applications not only to the Penn State device but also several other artificial heart designs currently undergoing clinical testing. Potentially the biggest benefit is in the development of a total artificial heart that will begin clinical testing in the early 1990's.

Of the nearly two million deaths annually in this country, a quarter of a million of those are from heart disease. Annual requirements for artificial hearts range from 17,000 to 35,000. The CFD research we're performing today at NASA Ames has the potential of impacting the future designs of these life-saving devices.

Thank you.

[The prepared statement of Mr. Kutler follows:]

125

#14

National Aeronautical and
Space Administration

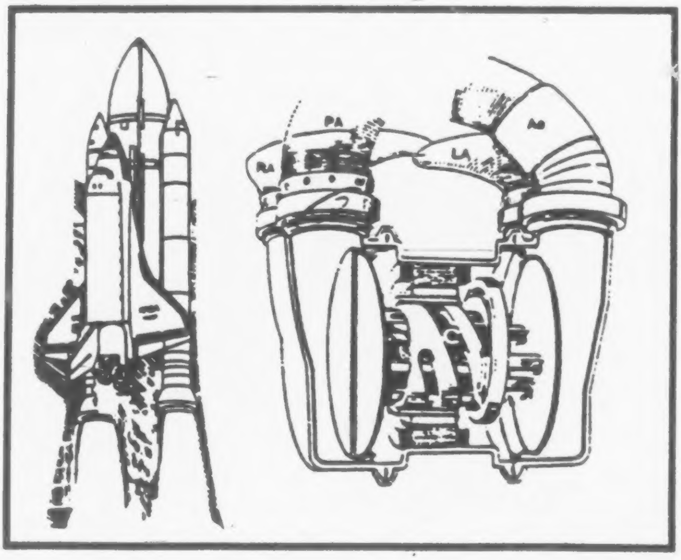
Hold for Release Until
Presented by Witness

April 13, 1989

Subcommittee on Space Science and Applications

Committee on Science, Space, and Technology

United States House of Representatives



Statement by:

PAUL KUTLER

Chief
Fluid Dynamics
Division
Ames Research Center

101st Congress

STATEMENT

OF

DR. PAUL KUTLER
Chief
Fluid Dynamics Division
Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Space Science and Applications
Committee on Science, Space, and Technology
United States House of Representatives

Mr. Chairman and Members of the Subcommittee:

I welcome this opportunity to appear before you to discuss an application of technology originally developed by NASA for the space program and sponsored by the Office of Commercial Programs, Technology Utilization Office. This project was designed to simulate flow in artificial heart devices with technology originally developed for numerically simulating the flow in components of the space shuttle main engine. It is a typical example of a good working relationship between a main line research organization and the Office of Commercial Programs.

The flow inside an artificial heart is complex, difficult to predict and hard to observe experimentally. It is known that blood flowing through such prosthetic devices can be damaged by fluid dynamic shear stresses. In addition, regions of separated flow caused by corners in the geometry are breeding grounds for blood clots that can lead to strokes. The mechanical check valves, that are an integral part of the artificial heart, are noisy but a comforting indication to the patient that the device is working properly .

It is important that the designers of these devices have a good understanding of the flow behavior in order to suggest configuration changes to improve the flow quality. To accomplish this, they can either perform experiments or utilize a numerical simulation technique called computational fluid dynamics.

Computational fluid dynamics (CFD) involves the numerical solution on supercomputers of a complicated set of mathematical equations that describe the behavior of fluids. Solutions from CFD are "information rich" and provide the designer with a complete description of the unsteady flow field of interest in contrast to what can be obtain experimentally. Changes in the geometry to enhance flow quality are easily implemented, cost effective and thus attractive to the developers. Although the simulation of one heart beat requires several hours of computer time on the world's fastest supercomputer, it provides otherwise unobtainable information.

This "spin-off" technology is being applied to simulate the flow in the Penn-State artificial heart, an electro-mechanical device powered by inductance from an externally carried battery. Adaptation of existing technology to the artificial heart resulted in two advancements that have "spin-back" applications for NASA for performance enhancements of the space shuttle main engine as well as other aerospace applications. The first advancement was the development of a time-accurate incompressible, Navier-Stokes solver, and the second was the development of a moving surface boundary condition procedure; both of which have been completed.

To accomplish this technology utilization project, a collaborative program was established among Penn State university, Hershey Medical Center, Stanford University and Medical Center, and NASA Ames Research Center. The technology pioneered to date is being used by the developers of the Penn-State heart to understand the flow behavior and compare it with their experimental observations. Eventually the developed technology will be transferred for use in the design of flow enhanced artificial heart systems.

The current CFD technology has applications not only to the Penn State device but also, several other artificial heart designs currently undergoing clinical testing. Potentially the biggest benefit is in the development of the total artificial heart that will begin clinical testing in the early 1990's. Of the nearly 2 million deaths annually in this country, a quarter of a million are from heart disease. Annual requirements for artificial hearts range from 17,000 to 35,000. The CFD research being performed today at NASA Ames Research Center has the potential of impacting the future design of these life-saving devices.

Thank you Mr. Chairman. That completes my prepared testimony. I would be happy to answer questions.

Mr. Nelson. Thank you, Mr. Kutler. We appreciate that.
Presenting the temperature pill, Dr. Eberhart.

STATEMENT OF DR. RUSS EBERHART, PROGRAM MANAGER, BIOMEDICAL PROGRAM OFFICE, APPLIED PHYSICS LABORATORY, JOHNS HOPKINS UNIVERSITY, LAUREL, MARYLAND, PRESENTING THE TEMPERATURE PILL

Dr. Eberhart. Good morning. I am Dr. Russ Eberhart from the Johns Hopkins University Applied Physics Lab and I think I have the smallest technology transfer device here this morning—(demonstrating)—an Ingestible Temperature Telemetry System that, when swallowed, telemeters out body core temperature accurate to within a tenth of a degree centigrade, and in fact we can make these as accurate as 1/100th of a degree centigrade.

The first five prototypes of this capsule were delivered to NASA in September of 1987 to Goddard Space Flight Center Technology Utilization Office at a cost to NASA of $75,000, so we're talking $15,000 a capsule at that point.

The NASA technology that was used to make these capsules included miniaturized circuitry, high-energy density batteries and magnetic telemetry links similar to what we use at APL on satellites that we build for NASA.

We licensed this technology with NASA to Human Technologies, Incorporated, of St. Petersburg, Florida, in March of 1988, and in November of 1988 the Food and Drug Administration approved the device for marketing. And they are currently being sold for a retail price of approximately $35 a piece.

This is the receiver computer unit that is used to receive the data and then download it into a personal computer after a day—(demonstrating).

And these are the devices that are actually being manufactured now and thousands of these capsules have been sold already. They've only been on the market for about five months, but they've already sold several thousand. In fact, their sales have exceeded their business projections.

The uses of the capsule currently include areas of sports medicine, OB-GYN, weight clinics, hazardous area biomedical monitoring and hypo- and hyperthermia research.

Currently we're working with a number of people in new areas for research for this capsule including people at Fort Knox, Kentucky in the biomedical monitoring from inside of armored vehicles of troops that are wearing protective gear, looking at monitoring their biomedical activity.

We are also working, again with NASA funding from Goddard Space Flight Center, on a three-channel capsule. This capsule will telemeter out not only temperature but also heart rate and electrogastrogram signals. We expect to have a prototype of that late this year or early next year.

One thing I'd like to say is that in two or three areas we are beginning an effort that I can only describe as technology transfer in reverse:

This capsule is now being proposed for use by crew members on the shuttle. Dr. Bob Phillips from Colorado State University is putting a proposal in to use this capsule on some upcoming flights.

In addition, we are in discussions with people, including Alan Bachick at Johnson Space Center to use a new version of this technology to telemeter the tire temperature and pressure on shuttle. So I think you can say this is sort of technology transfer in reverse.

The PIMS device you saw earlier from Johns Hopkins is being modified and updated for use as a multiple-channel biomedical telemetry system to go up in rhesus monkeys on board a joint French-U.S. mission to be flown in about 1992, again technology transfer in reverse, that is out of the Ames Research Center.

I'd just like to say one other thing: To me, NASA is people. And we keep saying NASA this, NASA that. To me, there's a person who never gets credited with—as he should be. There's a man at Goddard Space Flight Center who's had the vision to see these biomedical projects, he's had the commitment to back them up with dollars and he has the patience to stick with them through the years it takes, and that's Don Friedman, and he's here today and I'd just like to recognize Don.

Thank you very much.

[The Fact Sheet follows:]

127

#15

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL MARYLAND

FACT SHEET

Ingestible Temperature Monitoring System
(The Johns Hopkins University Applied Physics Laboratory)

Development:

The system was developed by The Johns Hopkins University Applied Physics Laboratory with funding provided by the Technology Utilization Office at NASA Goddard Space Flight Center, and delivered to NASA September 1987. The FDA approved marketing of the device November 1988.

Manufacture:

In March 1988 the technology was licensed to Human Technologies, Inc., St. Petersburg, Florida, where it is currently being manufactured for distribution by medical prescription.

Uses:

Because of the system's small size and accuracy (accurate to within 0.1 degree F.) it is expected to be used as a research tool to provide data, never before accessible, in areas such as medicine and manufacturing. Specific applications currently under use or consideration include spacecraft crew monitoring, sports medicine, obstetrics/gynecology, veterinary surgery and hazardous environment medical monitoring.

System Operation:

The capsule goes through the gastrointestinal tract, transmitting body core temperature using a magnetic telemetry link. The system can also be implanted, or vaginally or rectally inserted. Data can be received and processed in two ways: 1/using a portable unit that can be worn on the belt while it acquires data that can be printed out, or transferred to a computer, 2/using a personal computer directly to acquire, process and store the data.

Space Technology Utilized:

- the capsule's telemetry system, used to send information from the inner body to the computer or receiving unit, uses a magnetic telemetry link similar to those developed for satellites.

- the high energy density battery used in the temperature capsule was the result of technology developed for NASA satellites.

- low-powered electronic circuits, similar to those developed for satellites, were miniaturized enough to fit into the capsule and provide signal enhancement.

Continuing Research:

Work has been underway since mid 1988 on a three channel capsule for monitoring heart rate, temperature and electrogastrogram signals. This work is also funded by NASA's Goddard Space Flight Center.

For additional information please contact Helen Dugan Worth or Frank Proctor, (301) 953-5020.

Mr. Nelson. Thank you, Dr. Eberhart.

Does the pill dissolve, or does it just pass right on through the digestive system?

Dr. Eberhart. It passes through.

I swallowed the first one, by the way. My wife—we have a colander under the sink that will never be used for spaghetti again.

[Laughter.]

Mr. Nelson. Thank you very much.

Presenting the Automated Implantable Defibrillator, Dr. Heilman.

STATEMENT OF DR. M. STEVE HEILMAN, CHAIRMAN AND CEO, VASCOR, INC., PITTSBURGH, PENNSYLVANIA, PRESENTING THE AUTOMATED IMPLANTABLE DEFIBRILLATOR

Dr. Heilman. Yes. Thank you, Mr. Chairman, and members of the Committee. My name is Dr. Steve Heilman and I am President of Vascor, which is a Pittsburgh-based company that developed the Automatic Implantable Cardiac Defibrillator, or AICD for short. I'd like to address my remarks today—keep them brief and talk briefly in four areas:

First, what is an AICD; what clinical and medical condition does it treat; a few words about the history of the development of the AICD and what is NASA's role in that development; and what is the present status of the AICD?

AICD is a cigarette-package shaped device that is implanted in the outer wall of a human being. It's battery operated, hermetically sealed, much like the PIMS except that it treats a heart condition that is responsible for some 400,000 cardiac deaths per year in the United States. That condition is technically called tachyarrhythmia, which can either be ventricular fibrillation or ventricular tachycardia.

The device is located in the abdominal wall, has these electrode leads extending to the heart that pass current through the heart, the device monitors the heart continuously and determines the presence or absence of these lethal arrhythmias. Should one of the lethal arrhythmias occur, the device delivers an electric shock to the heart, breaking that arrhythmia.

Now the history of the Automatic Implantable Defibrillator:

Dr. Michel Mirowski is an Israeli cardiologist who emigrated to this country in 1968 specifically to develop his invention. At Intec, the company I represented, tied up with Dr. Mirowski in 1973 and we had a device which we believed was ready for human implantation in 1980. This gets to the question of NASA's role, which I will speak to in just a second.

We did implant the first device at Johns Hopkins University Hospital in February 1980 and we received an FDA approval on the device in May of 1985.

Subsequently, the technology has been purchased by Eli Lilly and Company, and a Lilly subsidiary, Cardiac Pacemakers, Incorporated, now provides that device commercially.

Now prior to implanting the first human device, with NASA sponsorship, we had the Applied Physics Laboratory of Johns Hopkins University perform a design review on the device. And they checked every component, they checked all of the manufacturing processes, made a number of suggestions and improvements in the device and, I think, substantially increased the reliability and safety of that device prior to the first human implant.

Subsequent to 1980, NASA—also with the help of Mr. Don Friedman and Bob Fischell, who spoke earlier—helped us a great deal with device enhancement, design device enhancements.

Now where is the Automatic Implantable Defibrillator today? Since the device was sold to CPI I'm not personally intimately familiar with exactly the status except I did check and there have been a total of 7,000 human implants to date of the device and sudden cardiac death has been reduced from an expected 25 percent to less than 2 percent per year in this patient population.

Thank you.

[The prepared statement of Dr. Heilman follows:]

#10

EXPANDED COMMENTS

NASA'S ROLE IN THE DEVELOPMENT OF THE AUTOMATIC IMPLANTABLE CARDIOVERTER DEFIBRILLATOR (AICD)

In 1967 Dr. Mieczyslaw (Michel) Mirowski, an Israeli cardiologist, immigrated to the U.S. with the hope of seeing his novel life-saving invention realized. His invention is known today as the AICD^{TM} automatic implantable cardioverter defibrillator.

The automatic implantable cardioverter defibrillator exists today because of the invention, perseverance and tireless dedication of Dr. Mirowski and those who believed in his invention enough to invest the time, money and other resources necessary to bring his invention to commercial reality. As will be described, NASA was one of the contributors to the commercial success of this new form of medical therapy. Thousands of people are alive today because of the pioneering work of Dr. Mirowski.

Although born in Poland's Warsaw ghetto, Dr. Mirowski's story is a classic American success story. Dr. Mirowski is the sole inventor of the U.S. patent entitled "Standby Defibrillator and Method of Operation" (RE. 27,757). Today, Dr. Mirowski is Director of the Coronary Care Unit at Sinai Hospital in Baltimore, Maryland, Professor of Medicine at Johns Hopkins University School of Medicine and a renowned cardiologist. The history surrounding the development and commercialization of this revolutionary and basic invention of an automatic implantable cardioverter defibrillator is a marvelous case study of the benefits of the United States patent system at work and provides an excellent example of how reapplications of technology originally developed by the National Aeronautics and Space Administration (NASA) can and do "spin off" into a wide variety of fields that affect the lives and well-being of the American people.

As the Nazis approached his home in Warsaw, Dr. Mirowski emigrated as a young boy to Russia, where he was forced to learn Russian quickly. As the war progressed, he looked for an opportunity to return to his Homeland. He tried to enlist in the Russian army, but was initially rejected when he naively admitted he was Jewish. Ultimately, he successfully joined the Russian Army and was part of the assault which recaptured Warsaw from the Nazis. To his dismay, he found that his entire family died in the Holocaust and with them died his beloved Warsaw.

He did not give up. He emigrated again; this time to Palestine. He decided to become a physician, but there were no medical schools in Palestine. Undaunted, he went to the south of France, rapidly learned French, and studied at Lyons. After gaining his medical degree, he returned to Israel. He had additional residency training in Mexico and at Johns Hopkins before returning once again to Israel, this time as chief of cardiology at a government hospital.

In the mid-60's, his chief of medicine and mentor, Dr. Harry Heller, suffered a nearly fatal episode of ventricular tachycardia (VT). Dr. Heller survived this first episode.

But with no effective drugs or other therapies available to treat him, Dr. Heller soon died of a recurrent attack. Stunned by Dr. Heller's untimely death, Dr. Mirowski began a study which revealed the magnitude of sudden death syndrome. For example, in the United States alone, it is estimated up to 450,000 sudden cardiac deaths occur each year. Only-about 20% of the patients survive this first attack. Moreover, 30% to 60% of those survivors die within the first year of the first episode. Today, sudden death is one of the leading killers of Americans.

In the late 1960's, Dr. Mirowski theorized a way to treat patients who survived the first episode. He conceived of an invention for an implantable defibrillator that would automatically and continuously monitor heart activity, sense the arrhythmia, and deliver an electrical shock from an energy storage device directly to the heart to convert the life-threatening arrhythmia to normal heart rhythm.

Dr. Mirowski became convinced that it would be impossible to develop his invention in Israel. He sold everything he had, and with $6000 in his pocket traveled to the United States with his wife and three small daughters. He obtained a medical position at Sinai Hospital. Another cardiologist, Dr. Morton Mower, became intrigued with Dr. Mirowski's invention and developed what continues to be a close collegial relationship. Working after hours in the basement of the Hospital, Drs. Mirowski and Mower commenced laborious trial and error experiments building device prototypes with off-the-shelf electrical components. A prototype was successfully tested in dogs late in 1969. By February 9, 1970, Dr. Mirowski submitted his first patent application to the United States Patent and Trademark Office (PTO). A patent was granted for his invention on October 26, 1971.

Dr. Mirowski did not have the funds necessary to develop or manufacture a commercial unit of his invention. He needed corporate support. The largest implantable cardiac device company in the world took a license, but later discarded the patent rights, since its marketing estimates for any product developed under the program were not very promising. At about that same time, a world renowned cardiologist published an editorial in an important medical journal sharply critical of the entire invention and concept.

Dr. Mirowski still refused to give up. As luck would have it, a mutual friend introduced me to Dr. Mirowski in Singapore at a medical conference. When I met him, I was president and founder of a small medical device company in Pennsylvania. While my company had no experience with implantable pulse generators, I soon shared Dr.Mirowski's vision. I risked the future of my company on the invention, relying on the patent rights to provide a period of exclusivity necessary to justify the development expense for commercialization. Research and development began in earnest.

A hermetically sealed, battery-powered device the size of a package of cigarettes, the AICD is surgically implanted in a patient's abdominal wall with leads extending to the heart. It continuously monitors the electrical activity of the heart for the presence or absence of life-threatening arrhythmias, or heart rhythm irregularities, known as ventricular tachycardia and ventricular fibrillation. If such an otherwise fatal arrhythmia is detected, the device delivers a corrective electrical shock to the heart, restoring a normal heart rhythm.

During the 1970s, my Pittsburgh-based company, Medrad, and its successor, Intec, took Dr. Mirowski's invention and developed it into an early-stage product. Prior to the first human implant at The Johns Hopkins University Hospital, NASA sponsored an independent and comprehensive design review of the device. This review was conducted by the Applied Physics Laboratory (APL) of The Johns Hopkins University. APL, having developed a number of NASA satellites, was and is a repository of expertise related to achieving very high degrees of reliability in the operation of sophisticated electromechanical devices. This NASA-sponsored collaboration between APL and Medrad optimized the device's component selection and the manufacturing processes used to achieve device safety and reliability. Subsequently, NASA and APL provided substantial assistance in product design efforts aimed at enhancing the functions of the AICD.

Throughout most of this early development, the invention continued to be met with skepticism and even derision. Still Dr. Mirowski persevered. Ultimately, the Food and Drug

Administration (FDA) allowed clinical investigation of this new therapy in the treatment of sudden cardiac death. After five years of clinical studies, the first generation device was approved for full market release.

In 1985, Eli Lilly and Company acquired the patents and AICD assets from Medrad/Intec. Lilly's subsidiary, Cardiac Pacemakers, Inc. (CPI), located in St. Paul, Minnesota, continues to provide the AICD while developing future models of this life-saving device.

To date, more than 7000 patients have received AICDs. For these patients, the first-year incidence of sudden death from arrhythmias has been reduced from an expected incidence of greater than 25% to an actual incidence of less than 2%. In recent years CPI has improved the device further, built acceptance for the therapy among physicians (cardiologists and electrophysiologists) and begun to recoup its large research and development expenditures. A second generation device, VENTAK^R was market released in 1986; a third, VENTAK 1550, was market released in 1988; and, a fourth generation device, VENTAK P, entered clinical investigation in 1988. Newer, and even more sophisticated, device systems are in advanced stages of development. While these newer products offer enhancements, flexibility and greater convenience, all built on Dr. Mirowski's basic idea since the bottom line of this kind of device is the capability to reliably terminate potentially lethal ventricular tachyarrhymias and ventricular fibrillation. All these devices have and must demonstrate this ability.

There are some clouds on the horizon which may inhibit the ability to reach all of the patients who may require this unique form of therapy. Currently, there are patients who are non-inducible during baseline electrophysiologic testing yet are still at significant risk of recurrent sudden cardiac death, who are excluded from coverage of AICD device therapy. This is because originally implantation of the AICD was seen as a "treatment of last resort" for patients who have documented episodes of life-threatening ventricular tachyarrhythmia or cardiac arrest not associated with myocardial infarction. In reality, the clinical experience as reported in medical journals and in the opinions of the medical community demonstrates that the use of the AICD device in treatment of these patients is superior to other available therapeutic modalities and it has been called the "gold standard" in the treatment of sudden death. Thus, a potential opportunity to making this therapy available to patients who need it is an expanded reimbursement policy so that appropriate therapy can be provided to these patients who remain at significant risk for sudden cardiac death. I believe that like so many obstacles, this hurdle too will soon be overcome.

By helping to assure the reliability and establish the credibility of this unique product during its early development, NASA has made an important contribution to this life-saving therapy. NASA had the foresight to commit resources when this now-proven device system was still in pre-clinical development stages. The American public, not just the space program, has benefitted from NASA's contributions.

Presented to the House of Representatives
Subcommittee on Space, Science and Applications
by M.S. Heilman, M.D.
Former Chairman & CEO, Medrad/Intec, Inc.
April 13, 1989

Mr. **Nelson**. Thank you, Dr. Heilman.

This particular plan, I understand, is in Mr. Walgren's district and Mr. Walgren had the privilege of presenting you the Exporter of the Year award several years ago, so we congratulate you.

And we're delighted to have you with us, Mr. Walgren, and delighted to have your constituent here.

Presenting the Below Elbow Prosthesis, Mr. Cardin and Mr. Belcher.

STATEMENT OF JEWELL "PETE" BELCHER, PROJECT ENGINEER, MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA, PRESENTING THE BELOW ELBOW PROSTHESIS

Mr. **Belcher**. Mr. Chairman, members of the Committee, we're glad to be here today to present this project we have going on at Marshall Space Flight Center.

This project was started as a result of Jim losing his hand in an unfortunate accident at home. We—well, when he first had this trauma he started looking for ways to give him some use of that arm, and there just wasn't anything to fit his lifestyle on the market.

So some of the engineers and technicians at Marshall started on our own trying to help him to adapt things to fit his lifestyle.

Mr. **Nelson**. Does Mr. Cardin work with you out there?

Mr. **Belcher**. Yes, he worked with us at the time.

Mr. **Nelson**. I see.

Mr. **Belcher**. He has since retired and is enjoying retirement.

Mr. **Nelson**. I guess you guys are real proud that J.R. Thompson was just named Deputy Administrator.

Mr. **Belcher**. We have mixed feelings about that.

Mr. **Nelson**. I'm sure you do.

Mr. **Belcher**. We're going to miss him at Marshall.

Mr. **Nelson**. I'm sure you do.

Mr. **Belcher**. But we are glad he is going to be here representing us, as well as the rest of the NASA centers.

But we looked at the robotics research that had been done at Marshall. We looked at the prostheses that were on the market: the electric hand—Jim did most of this research—we looked at the electric hand, the hook that's been in use for probably 50 years and there just wasn't anything there to fit him. This—well this is a good time, since he has this on.

This hook has the straps that come around the shoulders, it operates by moving the shoulders forward, as you see there. But this has many disadvantages: it gets in the way, the straps are hot, he can't reach up to open it, he can't reach down to open it because the shoulder straps slip off.

The Myelectric Hand is useful for someone who doesn't have a good hand, but for him it was just too fragile: it won't stand getting wet, the batteries have to be charged daily and replaced once a year; it just didn't fit his lifestyle.

So we started thinking of ways to do this and we looked at the end effectors that had been developed for NASA in the space program on robotics and used some of this technology and some of our own to come up with some devices that he can use. And some of these devices laying on the table he is already using and we hope to improve on them.

Now I'd like to stress that these are engineering working models. They're not finished products by any means. Because we're very young in this program and we expect this program to probably take two or three more years to get some real useful devices.

But two of the things that he is using now is the heavy lifting device that just replaces a hand for lifting a box, a rock, a stick of firewood or whatever, if he needs to lift something heavy. It does require a strap to keep from pulling it off.

Jim is an avid fisherman and hunter, so he had to have something to turn a fishing reel. So this little deal right here—(displaying)—does the job. He can fish all day with that and it doesn't bother him.

He had to have a chainsaw holder. And you think—when I told some of the people in my office that he needed something to hold a chainsaw, their first comment was The crazy thing has already cut one hand off, what is he going to cut off now?

[Laughter.]

Mr. BELCHER. But that's Jim Cardin.

And this can be adapted to hold a chainsaw, push a lawnmower...

Each one of these devices you see here is aimed at his lifestyle, but we think if they'll work for him they'll work for anyone.

What we hope to do from here is continue the development—oh, one other item that I want to tell you about before I go any farther is the device here that utilizes the rotation in his forearm.

He is fortunate in—if you can say that, in that he still has rotation in his forearm, and we want to use that rotation to open and close the hook instead of the cable around the shoulder; that eliminates the straps and the harness. And we think this has a lot of promise.

What we want to do is continue the development to where these devices are comfortable to wear and easy to use, obtain the necessary patents and get small business to manufacture them.

One of the problems here—and I'll do a little commercializing myself while I'm at it:

There's approximately 50,000, the best number we can come up with, 50,000 below the elbow amputees. This is a small number considering the number of people that are in the country. Most of these are crafts and trades type people who can't afford large medical bills. So this puts people like this at a great disadvantage in trying to replace a severed limb or a severed hand.

But we want to try to find someone to manufacture these at a cost that most anybody can afford them, obtain the necessary patents and license this information.

Now I stress simplicity: In our design, you've seen a lot of high technology; but we've found that high technology just wouldn't work in this situation.

But to show the simplicity: this is a one-handed man's knife. He can rock this thing to cut his steak, and fork it, pick it up and eat it. (Demonstrating.) That simple. And that was the idea in all of this prosthesis work that we've done.

Thank you.

[The prepared statement of Mr. Belcher follows:]

132

#17

BELOW THE ELBOW PROSTHESIS END EFFECTORS/TERMINAL DEVICES FOR UNILATERAL AMPUTEES

As a result of a fellow employee loosing his left hand in a serious home woodworking shop accident, several engineers and technicians at Marshall Space Flight Center (MSFC) started thinking of prostheses to give the amputee some use of the arm in a way that would fit his lifestyle. Prostheses that are available from the industry were investigated and it was discovered that very little is available except the cable actuated hook which most amputees use. There are battery powered electric hands, but they were found to be fragile and acceptable for only light duty work and activities.

The MSFC group determined that a single prosthetic terminal device would not be sufficient for all applications. Many of the approximately 50,000 hand and below the elbow amputees are crafts and trades people who work with their hands. It was concluded that persons leading active lives would need a functional low-cost prosthetic device for each type activity, i.e., gardening, golfing, using a chain saw, heavy lifting, fishing, hunting, or other activities requiring two hands. It was also determined that these prostheses were not available commercially.

At Marshall, some research had been conducted on robotics and small mechanical mechanisms or end effectors for the space program. This technology was reviewed to see what could be adapted to the real-life situation of the amputee.

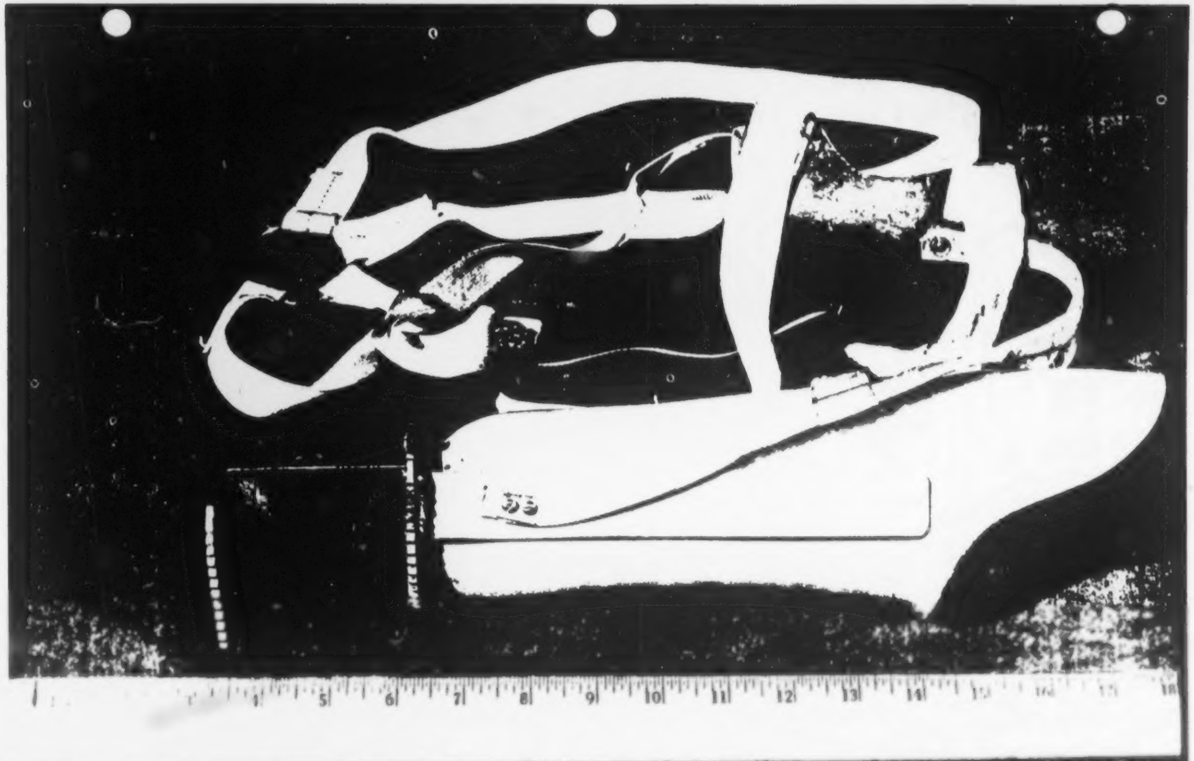
The amputee had retained the arm side of his wrist and could rotate his forearm. Early in our investigation, we emphasized using this rotation capability to actuate any operable prostheses, with quick-change end effectors if these could be practically designed and fabricated.

To date, the group has developed five dedicated prosthetic devices and one general purpose prosthesis and the amputee is evaluating these engineering prototypes to determine what refinements need to be made. The group is attempting to design an alternative to the shoulder harness used on the commercially available cable actuated hook prosthesis, since the shoulder harness is hot and the straps are binding and uncomfortable. Where heavy lifting may pull off the device, a shoulder harness will be necessary. These devices, shown in the attached photographs, are:

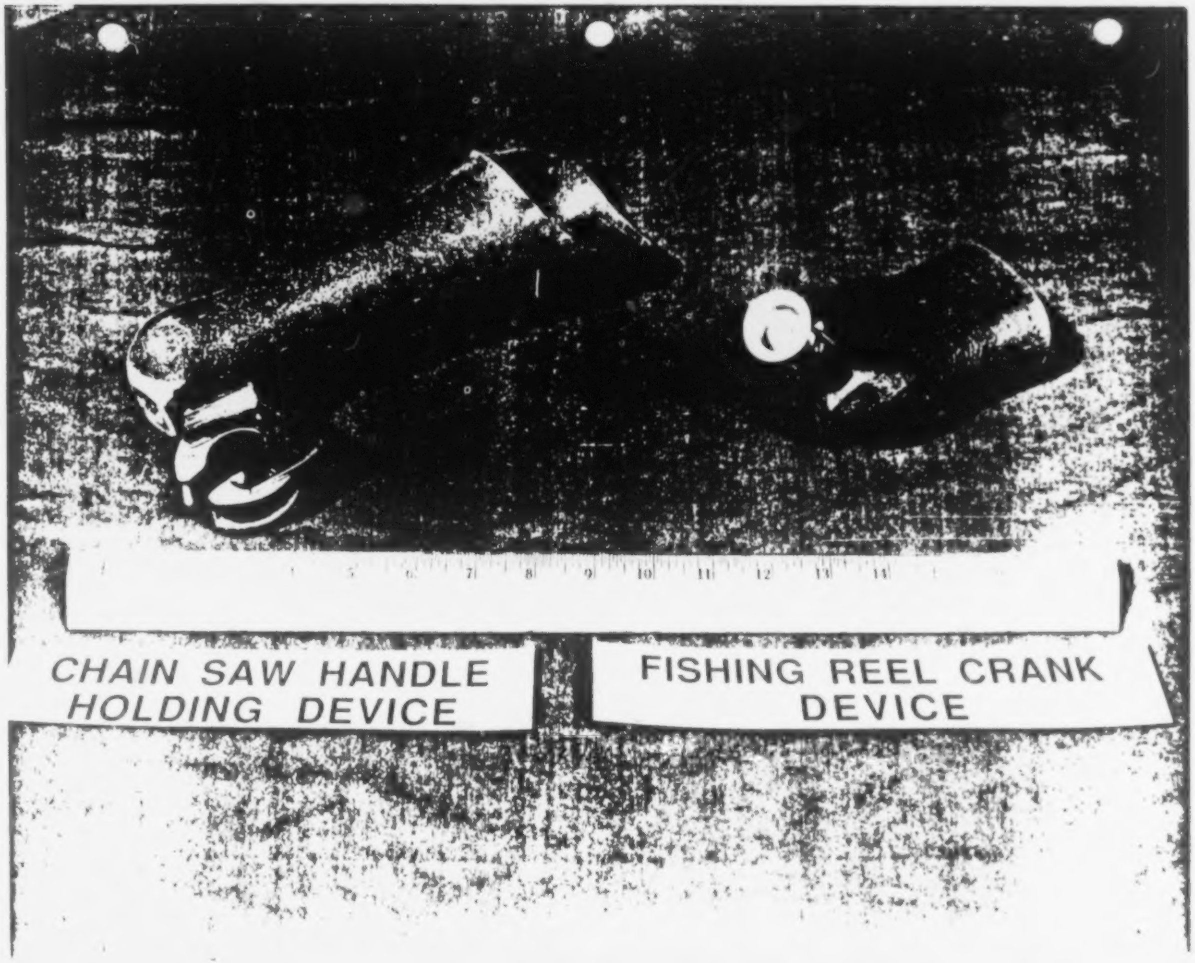
1. Heavy lifting device with shoulder strap
2. Fishing reel crank turning device
3. Chain saw handle holding device
4. Round handle holding device for golf club, garden tools, etc.
5. One-handed meat-cutting eating utensil
6. General purpose lightweight rotationally actuated device without shoulder harness.

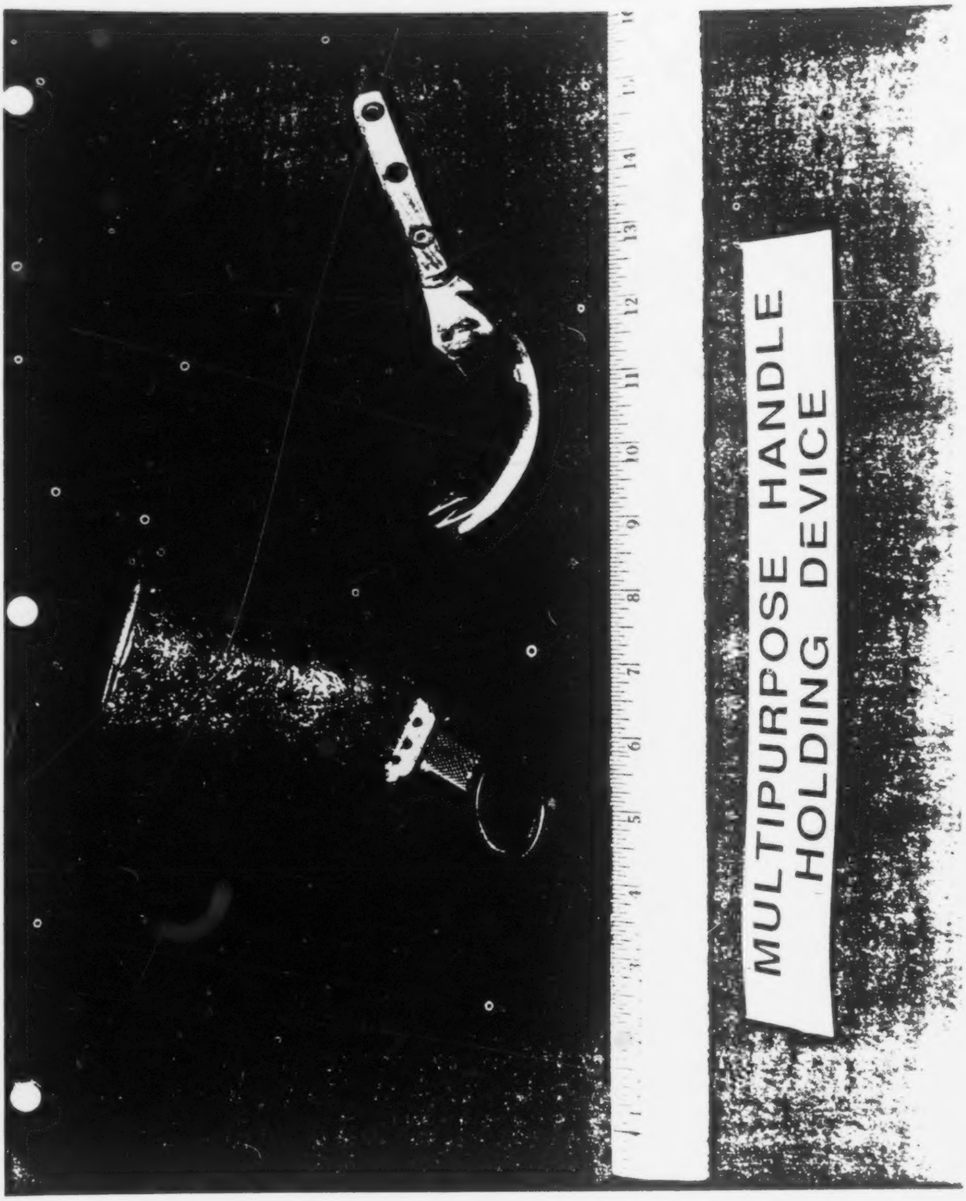
The group plans to continue this development work to a point that the devices are completely functional and comfortable to use and can be manufactured at a low cost. The necessary patents will be obtained so that this technology can be licensed by the Government to small business manufacturers.

For additional information on this project, please contact the NASA/MSFC Technology Utilization Office, 205/544-0962 or FTS 824-0962, George C. Marshall Space Flight Center, Huntsville, AL 35812.



HEAVY DUTY LIFTING DEVICE


CHAIN SAW HANDLE
HOLDING DEVICE
FISHING REEL CRANK
DEVICE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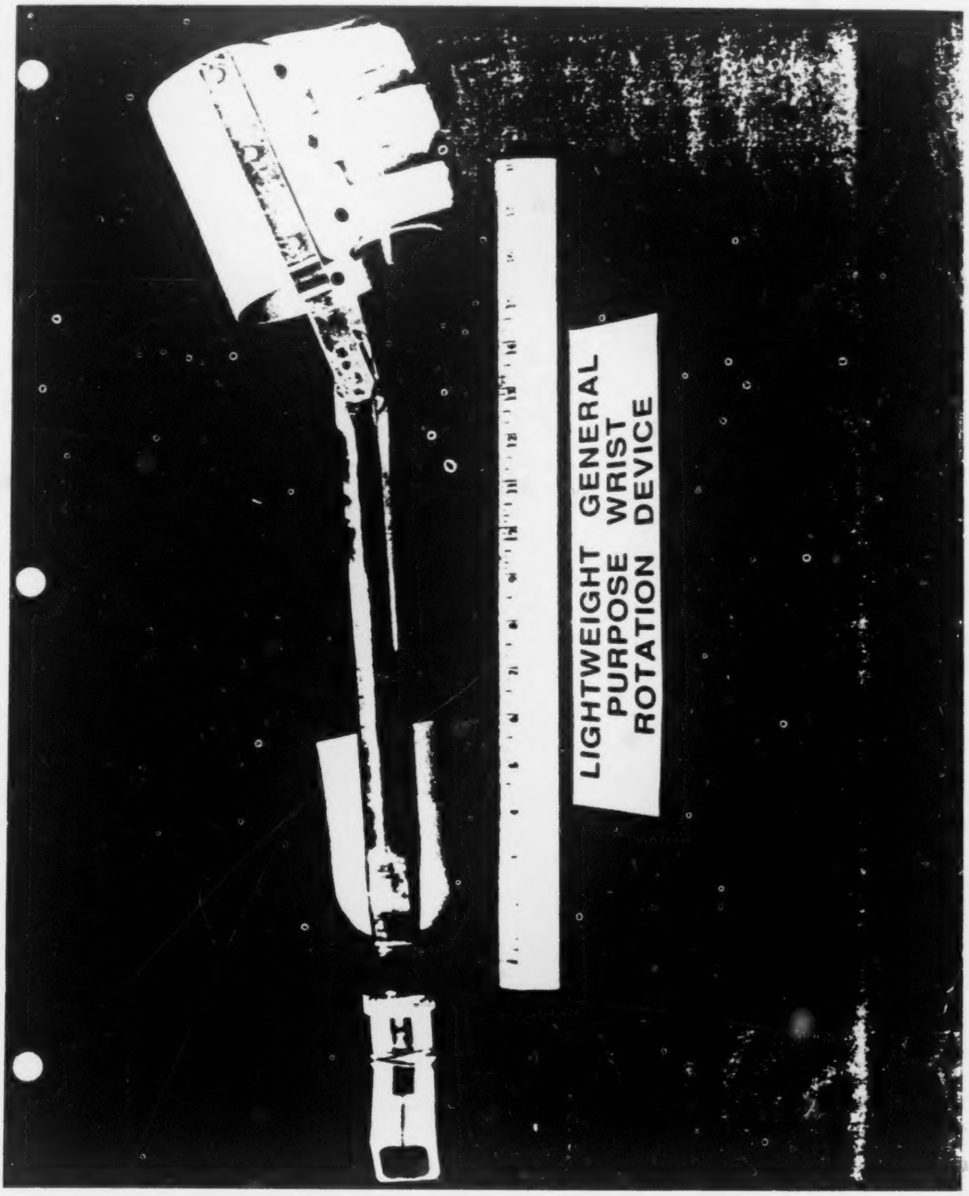
LIGHTWEIGHT GENERAL
PURPOSE WRIST
ROTATION DEVICE

Mr. NELSON. Well thank you very much, Mr. Belcher, and Mr. Cardin. We appreciate this very much. It's a whole new education to the Committee here.

Presenting the Aquaspace Water Filter, Mr. Pedersen.

STATEMENT OF MIKE PEDERSEN, PRESIDENT, WESTERN WATER INTERNATIONAL, FORRESTVILLE, MARYLAND, PRESENTING THE AQUASPACE WATER FILTER

Mr. PEDERSEN. Mr. Chairman, members of the Committee, it's my pleasure to be able to present to you today a direct spin-off from the NASA program in an application to water.

What's been seen today is that many of these different devices that have been shown are basically along the lines of the old adage of necessity is the mother of invention.

Essentially the Aquaspace Water Filter got its origins in the sense that, in looking around what was currently available in the common market or in the industry for a product to distribute, and given the applications that we were looking for, one didn't exist. And that led us to start to look, well what type of technologies are there available that we might be able to utilize in the production of a more significant application for the water industry. And that led us to look at some of the work that NASA had done.

The earlier NASA work that we looked at was silver work where they used silver to help the bacteriostatic properties of carbon, and then we started looking into further applications for the adsorptive and absorptive capabilities of medias for chemical removal. And it is that type of application that we were able to incorporate into the filter that we'll talk about today.

Essentially the waters of America are unfortunately becoming contaminated at an ever-increasing rate, and the ability to remove these contaminants are meeting an ever- increasing challenge. And to that challenge we have to look at both—not only organic, but inorganic type compounds that have to be removed.

Now prior to this conception, there were three basic types of water filters that were available for the home owner or even for commercial use: there was, for example, the reverse osmosis, distillization units and the granulated activated carbon.

Carbon units by themselves were very effective against the reduction of taste, odor and chlorine; however, when significant amounts of chemicals were infiltrated into the water, they didn't hold up. So that's what spawned the greater, I would say, need for the reverse osmosis or distillization type of unit. Unfortunately the latter are quite cumbersome, generally more expensive and unfortunately are very limited to the type of product water they can produce over a given time.

So that leaves you with a dilemma. And the dilemma was: how can you remove a high rate of chemicals in a quick period of time? And that's what got us into working with some of the NASA spin-off, the ability to increase a type of media. We call it a charged, modified, composite blend media.

What this media does is it enables us to remove these increased contaminants at a level that normally is reserved for the more expensive reverse osmosis or distillization. And a unique property here is that we've groomed it so that it will leave in the essential minerals—which is a very common factor in plain carbon, but not found in the reverse osmosis and distillization.

Now where this will have a direct application for the home owner is that unfortunately it is starting to be proven that the primary root of exposure to many of these volatile organic compounds that are found in most of the water supplies is not through ingestion, as normally thought of, but actually through inhalization.

Now how that has an application to water, unfortunately, is that 50 percent of these chemicals will volatize during normal household activities: such as showering, running your washing machine, dishwasher, things like this. And unfortunately the levels of exposure actually approach approximately six times greater from what you breathe than what you drink. So even if one was to turn to, let's say, bottled water as a solution to that problem, they would actually still get six times the level from just living in their home.

What this means is then that one must think of an affordable alternative to be able to remediate this problem for the house, and the only solution is a whole house situation, where you actually remove the chemicals as they come in the water—the water comes into the house.

To this end we've been able to develop this media and place it into a point of entry filter. And that actually has probably one of the greatest implications.

It's still a little young, the media that we've developed, we've spent a number of years doing it. It is commercially available on a limited basis. In the local area, we've—actually it's been placed in the Blair House and in EPA headquarters because it's met with that much of an ability to do the job that requires—

Mr. NELSON. Let me ask you, how did you come in contact with this technology that had been developed by NASA, how did you learn about it?

Mr. PEDERSEN. Well the way I learned about it was out of pure frustration. Personally, I was a Naval aviator and I was about ready to get out and I was looking for a water filter as an advocation to beginning into the airlines.

And in going around and talking to the different type of water companies that, of course, all had very unique products of their own, I was looking for something specifically that would give a higher chemical removal but yet leave in as many of the essential minerals as possible.

Out of frustration, I—again, probably because of the aviation background—I contacted NASA to see what type of work they were doing in the space program, because I figured if there's anything state-of-the-art, that's where to look, and that's where I found it.

And it was a combination of the NASA technology plus our own technology that resulted in—well we call it the Aquaspace compound because it does have its roots there, so we Federally registered it, and that's where it came from.

Actually, the biggest application was the fact that we can use this media in anything from a small little pocket filter for camping, for people that are afraid that maybe the water that they're getting may have a little bit of oil or something of that nature in it—(displaying product).

A little bit larger, and yet still versatile is a pour through; this collapses down—(displaying product).

And on up to the standard 9-3/4 type cartridge that is currently the standard in the industry. And as I said I think the ultimate common everyday appliance of the Nineties will be a whole house filter, which we do have one picture, it was kind of big to bring here today, but that probably will be a common appliance, just like a heater or an air conditioner in a home.

Mr. **Nelson**. Thank you very much.

Mr. **Pedersen**. Okay. Thank you.

Mr. **Nelson**. We appreciate this.

Presenting the Bon Del Water Filter, Mr. Ray Ward.

STATEMENT OF RAY WARD, PRESIDENT, WATER FILTER COMPANY OF AMERICA, NATIONAL CITY, CALIFORNIA, PRESENTING THE BON DEL WATER FILTER

Mr. **Ward**. Thank you, Mr. Chairman, and the Subcommittee. It is my privilege to be here.

And the thing I want to start with today, is my company started some 12 years ago as a direct result of the NASA program. I was a body and fender man, a high school dropout, but I didn't like the taste of water.

[Laughter.]

Mr. **Ward**. And I wanted to do something about it. I figured they made oil filters and such as this and I thought Golly, I can make a filter.

So I started in my kitchen, and I made about 148 ways it didn't work, contacted NASA, got a data brief from them that was written in 1968—this was in 1977 that I was doing this, so the brief had laid around for some time.

The big problem with filters at that time—not unchanging—is the fact that charcoal, as well as it—or carbon, granular activated carbon, different resins, have ability to adsorb and absorb and I won't go into a lot of technicality here because you won't understand it anyway. But I'm just grateful for all of this.

But because of the excellent particle retention of these medias, they actually trap microorganisms that bacteria literally thrive upon. As a result of it, a water filter sitting overnight, there's a good chance that it could be more harmful the next day than the benefit that it's doing with of the rapid growth of bacteria.

The testing we had to do to approve our product in the State of California was after half of life we had to inject our product with 1500 microorganisms of bacteria and then a charcoal filter with the same amount; ours had a residual of less than one bacteria—I call it the paraplegic bacteria, it is awfully damaged I guess—but had less than one appear from our unit. There was 1,500,000 growth in the charcoal filter.

So with that knowledge I went on and I continued to build and build and we've now—I want to thank NASA publicly for this opportunity, because I started out in this business with $27, armed with a dream of trying to build something, with sales after 12 years exceeding $200 million, we sell to Saudi Arabia, we sell to Beirut, Lebanon, we sell throughout Europe, and we've just—where was the latest place we've sold? Oh, Greece and Turkey, throughout Europe, of course, and in Turkey and Egypt.

And we're excited about what's happened. And it's a direct result of NASA. And my gratitude goes out that only in America can something like this happen. And I'm grateful for the opportunity to be here today. It's a privilege for me. I never thought in my life I'd ever have an opportunity to be with all you sophisticated people here. But it's my privilege, and I'm grateful for it. And thank you very much.

Mr. NELSON. Thank you.

Mr. WARD. By the way, our product is over here for display. We do have an in-line unit for refrigerators, we have the countertop unit which we've found has become the most popular because it's mobile and we have a mobile society. And the unit lasts five years with only minor cartridge rechanging.

That's all the commercialism I'm going to do here. I'm just grateful to be here. And thanks again to NASA for making this available to me and changing my lifestyle.

Thank you.

[The prepared statement of Mr. Ward follows:]

147

APRIL 7, 1989

#18

NASA TECHNOLOGY SPINOFF PRODUCT
BACTERIOSTATIC WATER TREATMENT DEVICE

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The BON DEL BACTERIOSTATIC WATER FILTER was developed by RAY E. WARD in late 1977. The need for a quality, compact home water treatment device was just becoming evident, with the awareness that the municipal treated water in most cities was tasting bad and looking worse. Ray Ward's drinking water in Mesa, Arizona was terrible and he began to research the existing filters that were available.

Granular Activated Carbon (GAC) filters in one form or another were available. Most of them were being made of plastic PVC pipe and charcoal. They were poor in quality and the performance was questionable, even though they were making outrageous claims. GAC or charcoal filters were found to actually grow bacteria at a very accellerated rate, then being more harm than good. Because of the excellent partical retention of GAC and charcoal, it actually traps micro-organisms that bacteria thrive on, and would literally become an incubation bed. In one California test, a GAC filter was injected with fifteen hundred micro-organisms that multiplied_into one million five hundred thousand per mil-liter over a 24 hour period. With that knowledge, GAC or charcoal alone was out of the question for home use. During periods of time when the filter is not in use, such as overnight or when on vacation, a potential buildup of bacteria trapped in the filter can multilply and become a considerable amount.

Ray Ward had read where NASA had worked on a filter for the Space program, a small compact filter that actually killed bacteria in the filter bed. He wrote NASA inquiring about this new technology and began work on his first filter. Now marketed worldwide under the trademark name BON DEL , the technical research from NASA made it possible to create a much needed product, a filter device that was bacteriostatic, in other words, it does not allow bacteria to grow within the filter bed. BON DEL's patented Hydro jet scrubbers eliminate back flushing forever. The Hydro jet centrifugal action begins when water enters the unit. Heavy debris and contaminents are force away from a patented five micron filter, allowing only the debris-free water to reach the media of the unit. The water then passes through 1100 cubic centimeters of torturous scrubbing stations, inhibiting the growth of bacteria and removing chlorine and other chemicals that are found in municipally treated water. The filter, however, does allow the much needed minerals to pass through. 1.05% silver is attached to the GAC and produces a residual silver ion of less than 50 parts per billion, as per EPA standards.

BON DEL™, a product of WATER FILTER COMPANY OF AMERICA in National City, California, is ongoing proof that our Space Program helps everyone. The good drinking water benefits people, there are financial benefits for thousands of Distributors, and WFCA employs a number of people in Manufacturing, Engineering, and Research and Development. With nearly ten-million people enjoying the great tasting water, the Space program has contributed a great deal to America and the world. The BON DEL™ has been sold in the United States, Canada, Egypt, Beirut, England, Greece, Japan, Turkey, Saudi Arabia, Sweden, just to name a few of the countries around the world who are also benefiting from NASA Technology.

WATER FILTER COMPANY OF AMERICA
310 WEST 35TH STREET STE.B
NATIONAL CITY, CAL. 92050
(619)427-9555

RAY E. WARD
PRESIDENT, CHAIRMAN OF THE BOARD

Mr. **Nelson**. Thank you, Mr. Ward.

Well you can see it's been a great day. We're going to bring this hearing to a close, but now the hands-on experimentation starts. So you all are welcome to at your leisure get a personal demonstration of all of these spin- offs.

We wanted to have this as a forum to try to communicate just how important the research and development and the application of that R&D from the nation's space program is to our everyday life and to our quality of life and the kind of hope that we have for the future improvements to our quality of life. This is a major part of this nation's space program.

Mr. Rose, I'll give you the last word.

Mr. **Rose**. Well we're delighted that the opportunity was provided for us to do this. As I said, we believe that there's somewhere on the order of 30,000 applications that have been derived from the space program. You've seen a number of them today, and I think we're going to see significantly more in the future.

I do think it is becoming a more important part of our whole competitive posture in this country is our ability to identify technologies and transfer them rapidly into our industries. And I think there's a lot more we can do within NASA, within the government, to try to make this happen and we're dedicated at NASA to moving this forward and moving it aggressively forward.

Mr. Chairman, it's been our pleasure to be here today and thank you.

Mr. **Nelson**. And you must have one of the most satisfying jobs in government, that you can see this happen in front of your very eyes.

Mr. **Rose**. We're doing some very interesting things and I'm enjoying it, yes.

Mr. **Nelson**. And we thank you.

And thanks to everybody for their participation and the meeting is adjourned.

[Applause.]

[Whereupon, at 12:50 p.m., the meeting of the Subcommittee was adjourned.]

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